Topologically Optimised Cast Glass Grid Shell Nodes

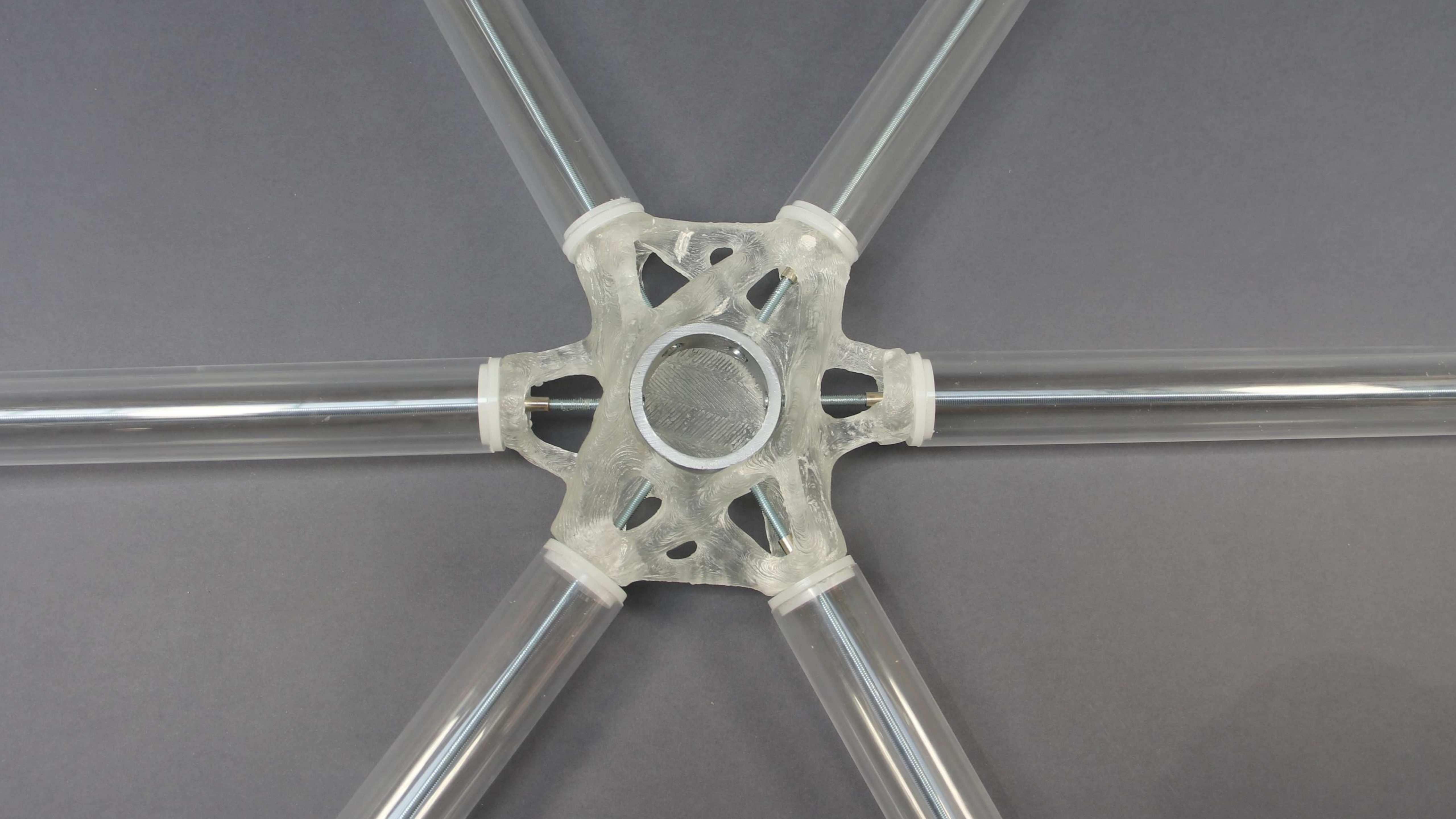
P5 presentation

Wilfried Damen 4277031

Mentors
Faidra Oikonomopoulou
Structural Design

Michela Turrin
Design Informatics

External Examiner
Erik Louw
Urban and Regional Development

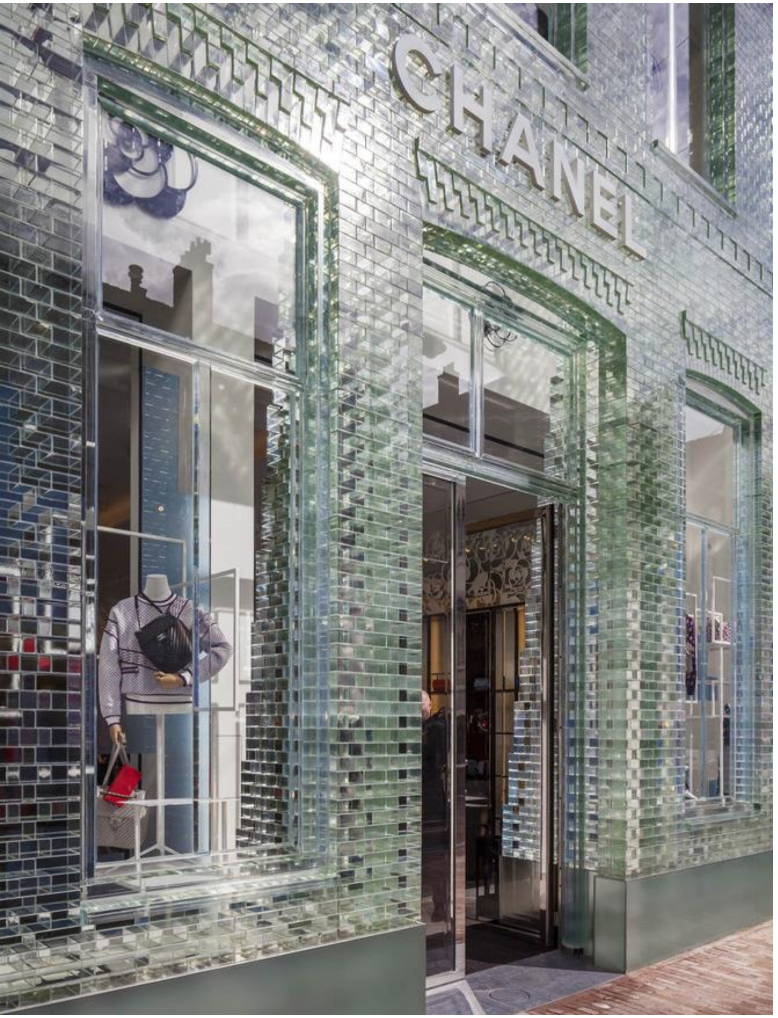


Goal

Explore the potential of topology optimisation as a design tool for complex structural cast-glass elements with a reduced annealing time

Goal

Explore the potential of topology optimisation as a design tool for complex structural cast-glass elements with a reduced annealing time



cast glass architecture

cooling glass

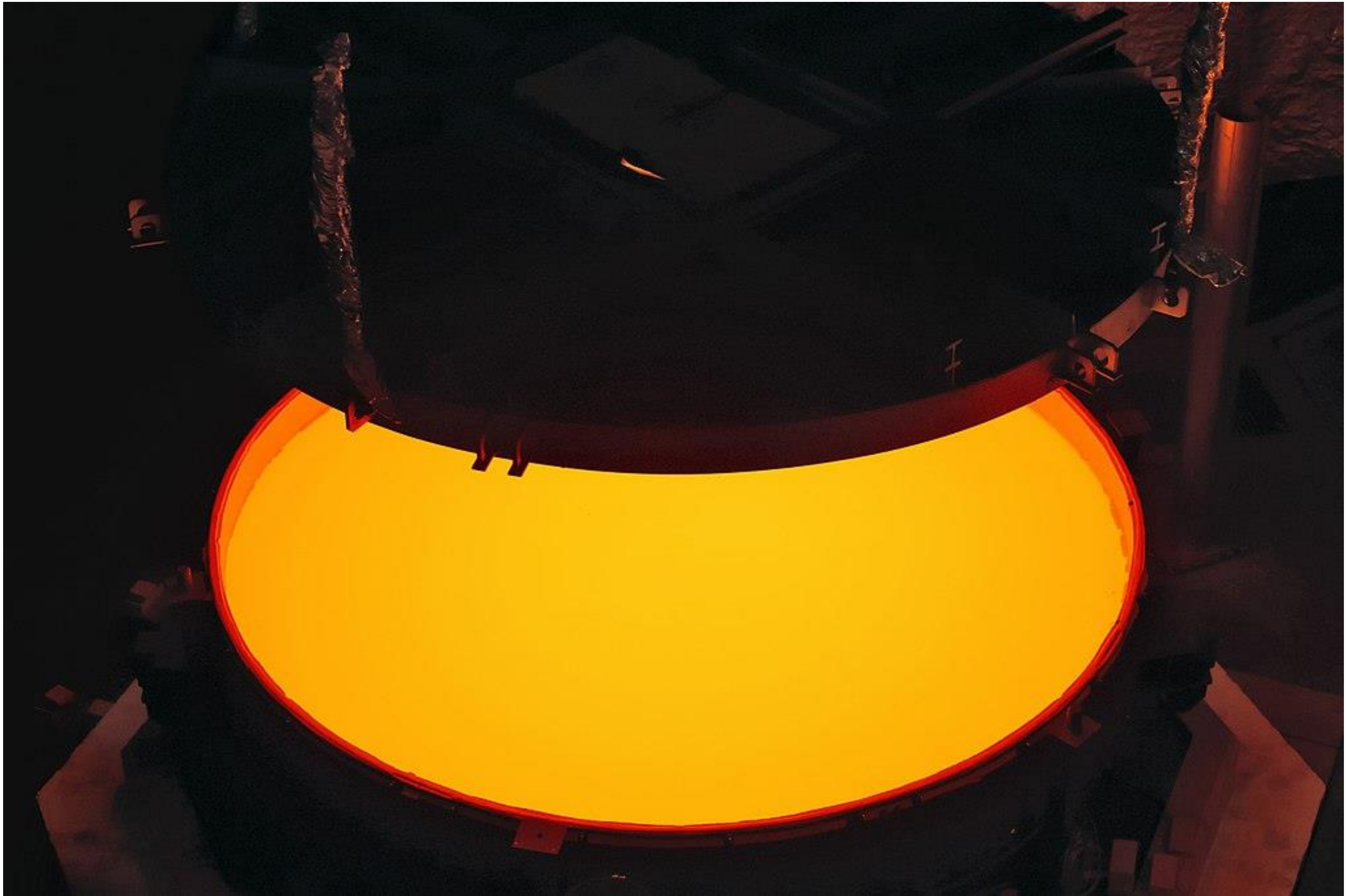
cooling glass

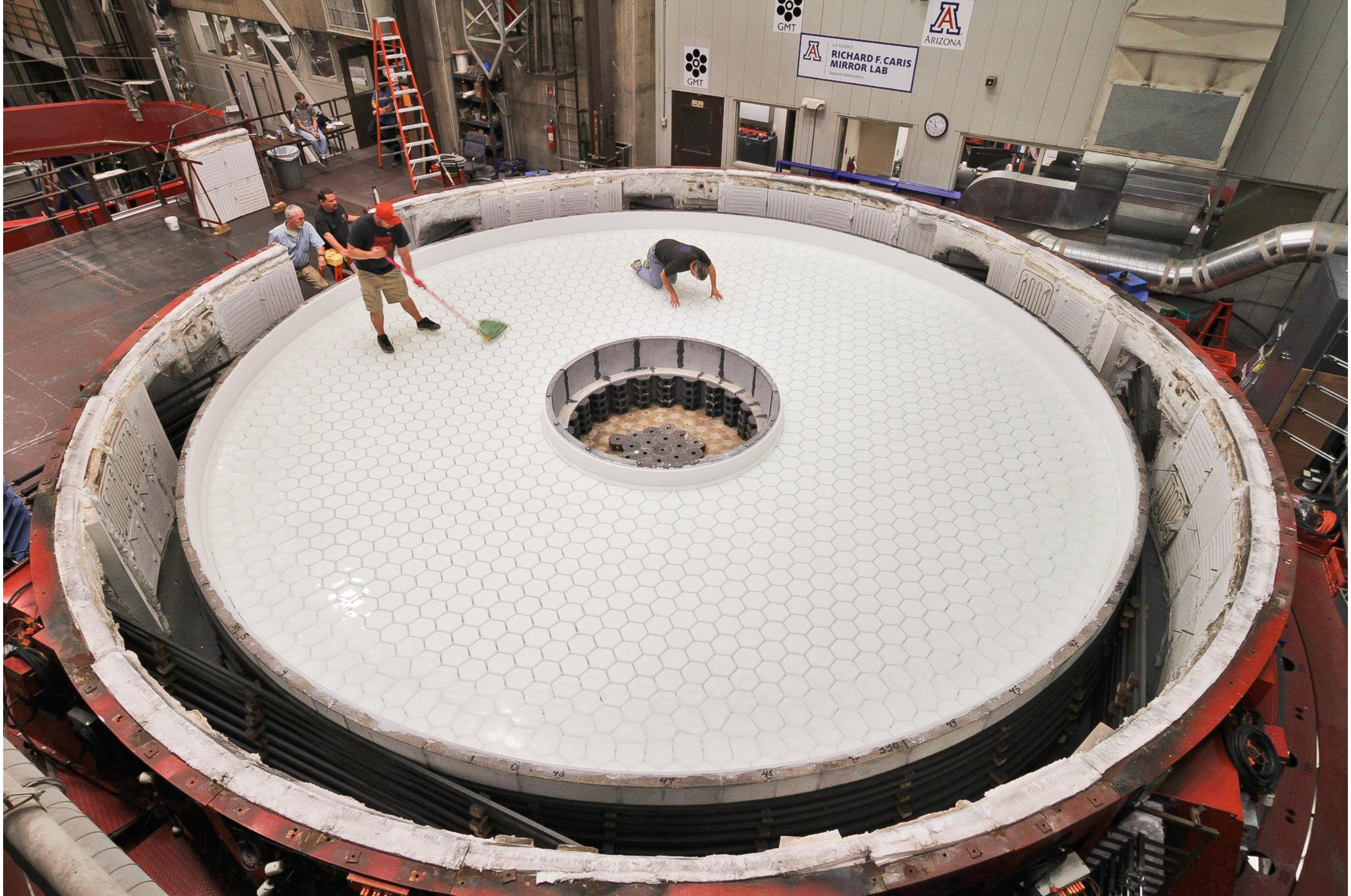
cooling glass

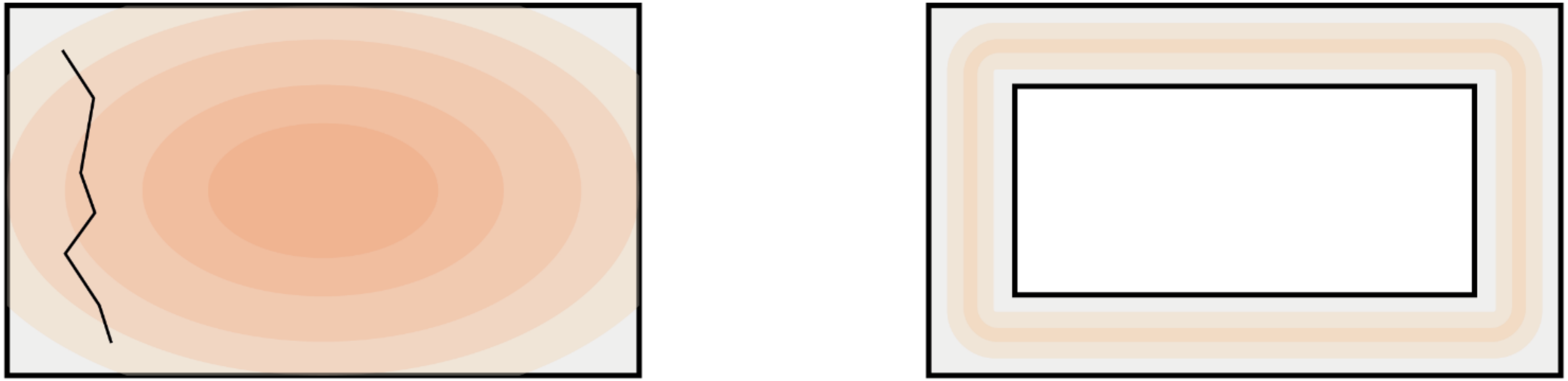
cooling glass

Annealing
Gradual cooling to prevent internal stresses

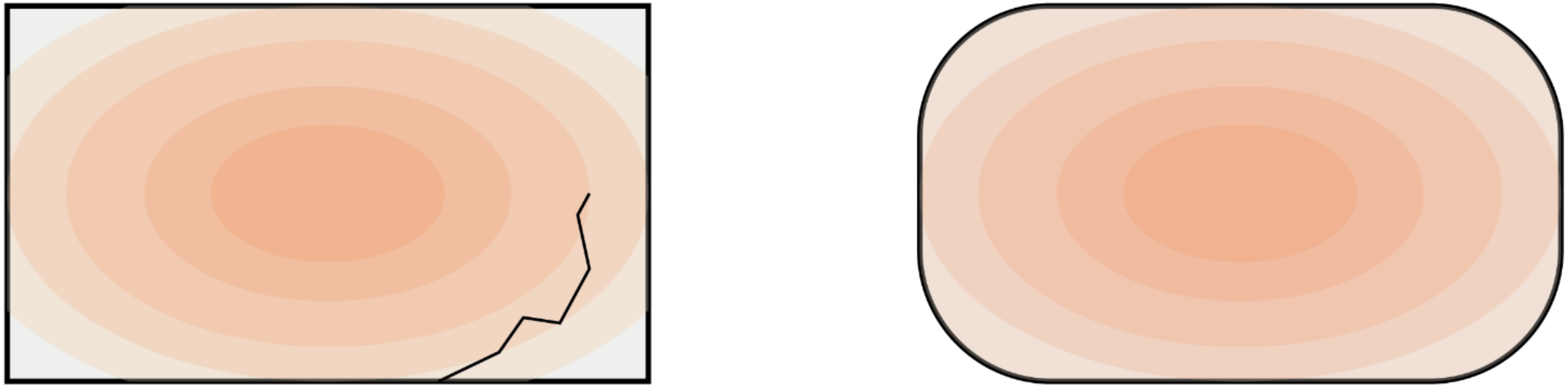
How to design for annealing?



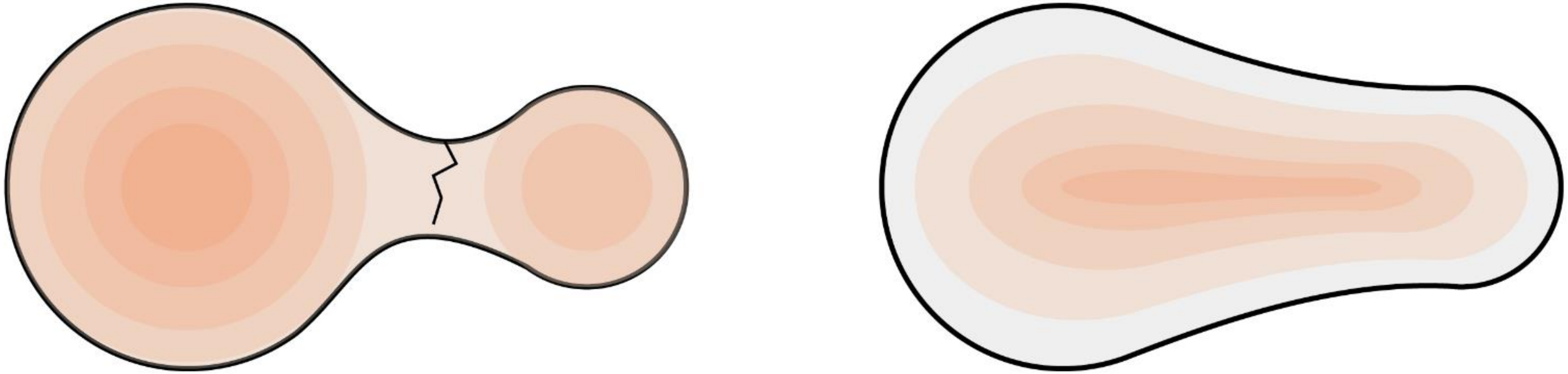

GMT
GMT
RICHARD F. CARIS
MIRROR LAB
ARIZONA



mass reduction



rounded shapes



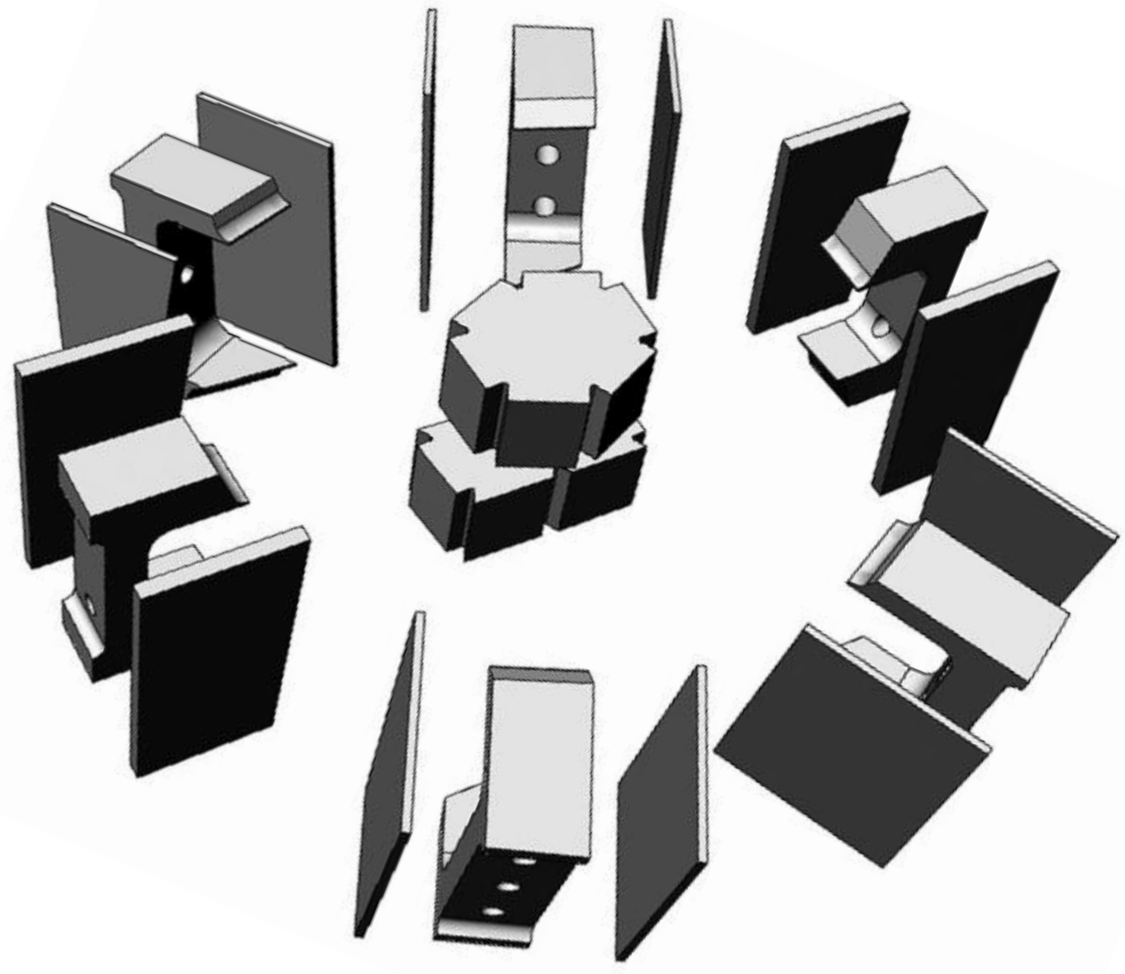
equal mass distribution

Topology Optimisation

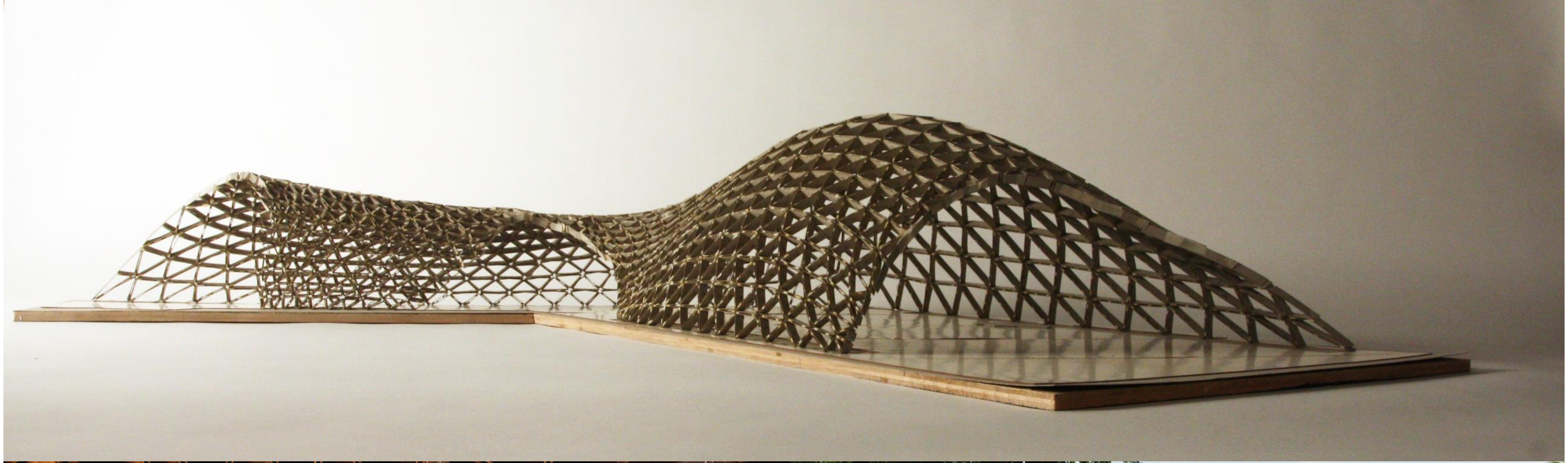
Topology Optimisation

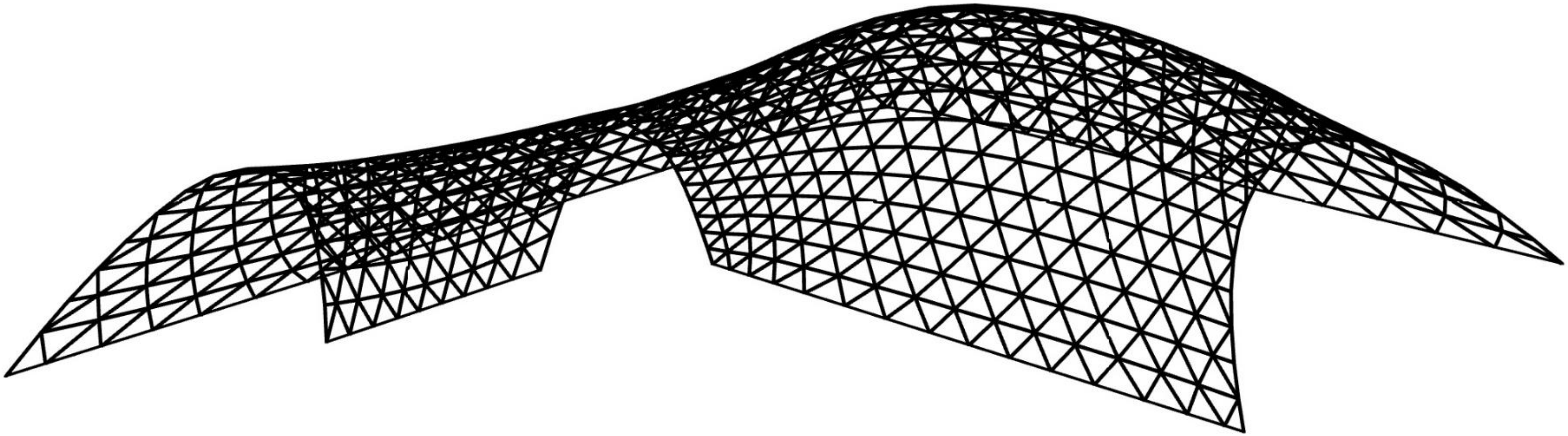
Research question

What is the potential of using Topology Optimisation as a design tool for a structural cast glass grid shell node that is optimised for fabrication, structural behaviour and assembly?

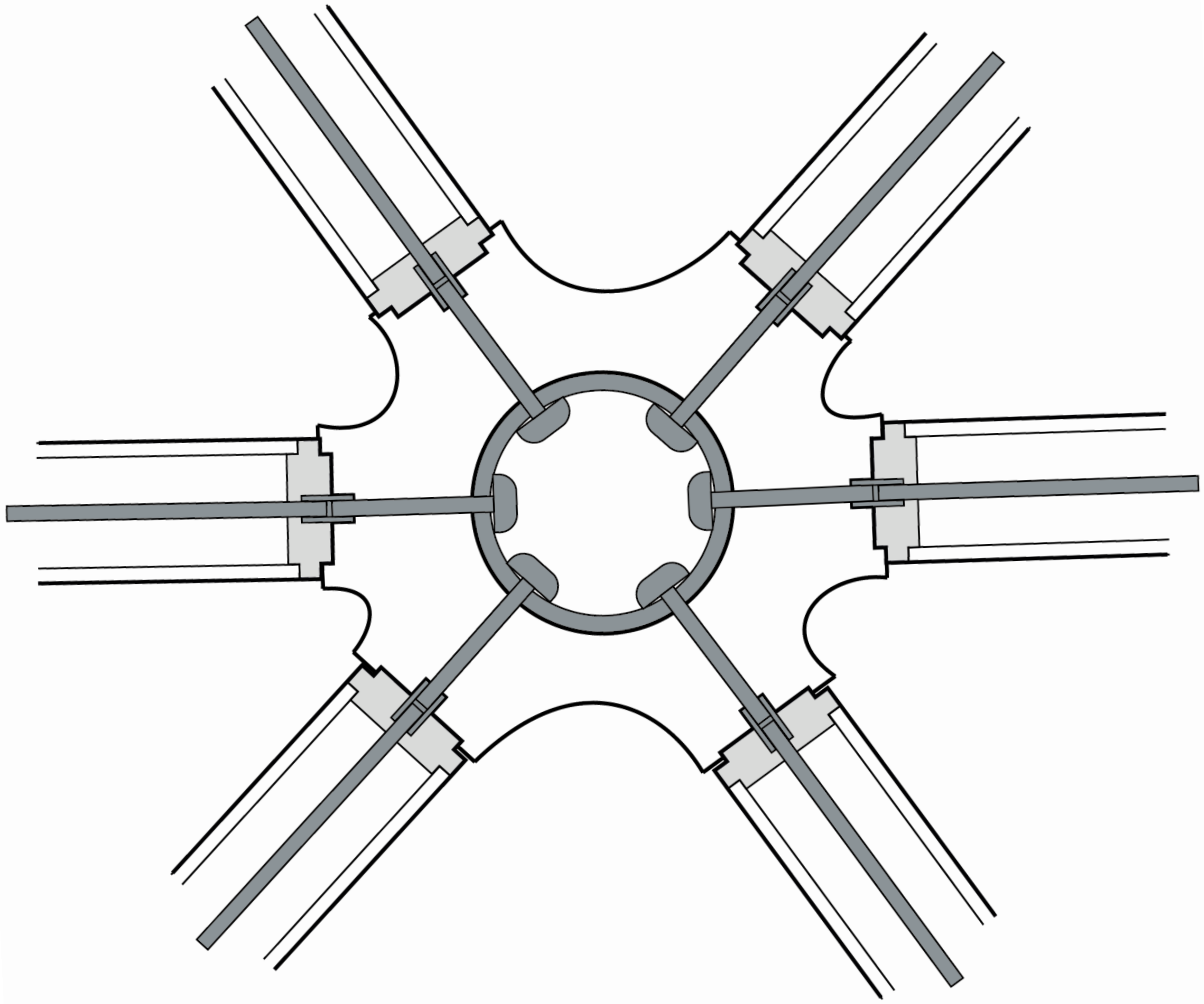


case study design



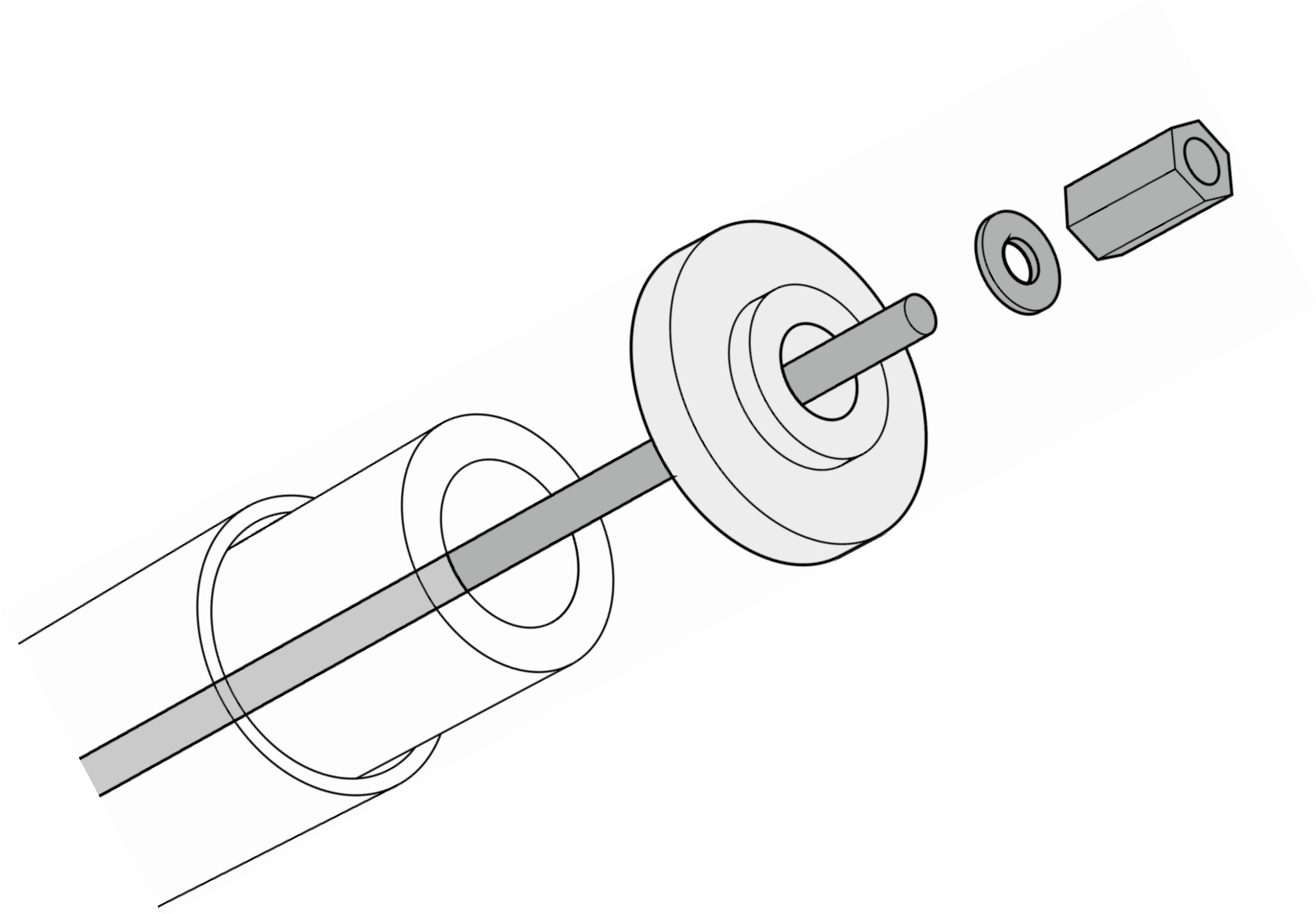


glass beams



assembly design

metal end caps

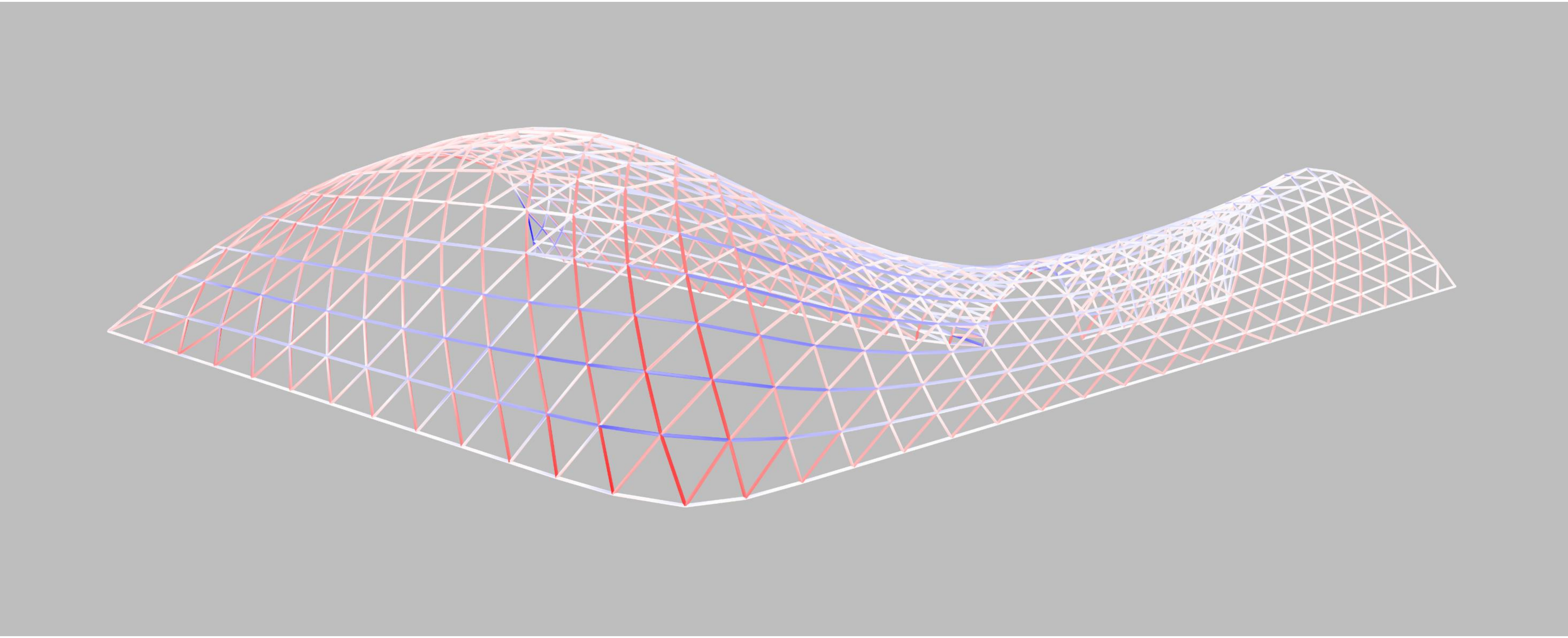


POM end caps

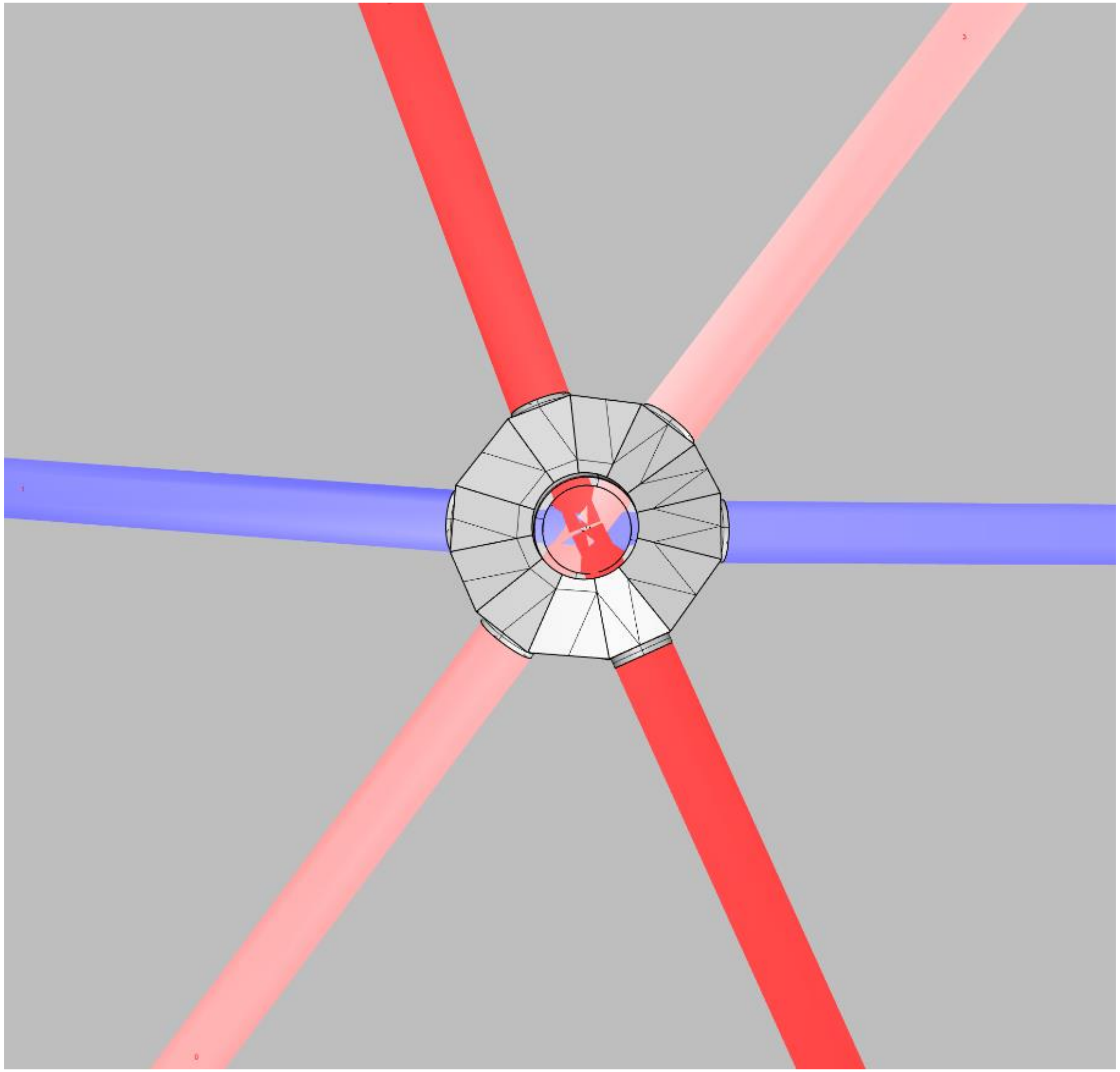
Topology Optimisation

Optimisation goals
Minimising mass
Element thickness 15-30 mm

Maximum tension 20 N/mm^2
Maximum compression 200 N/mm^2



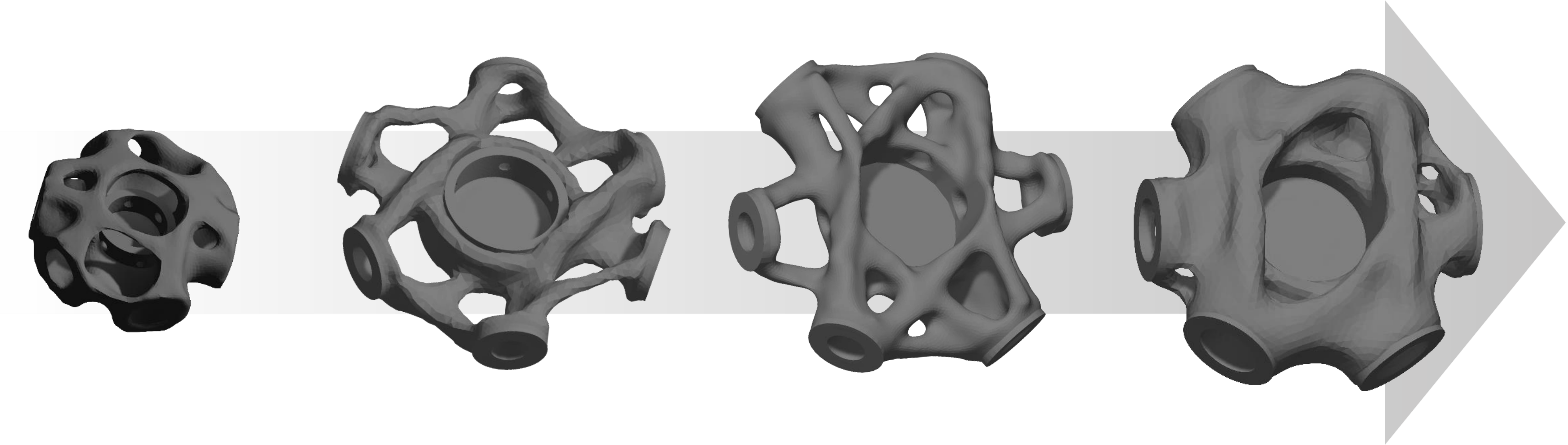
Karamba3D structural analysis



J8

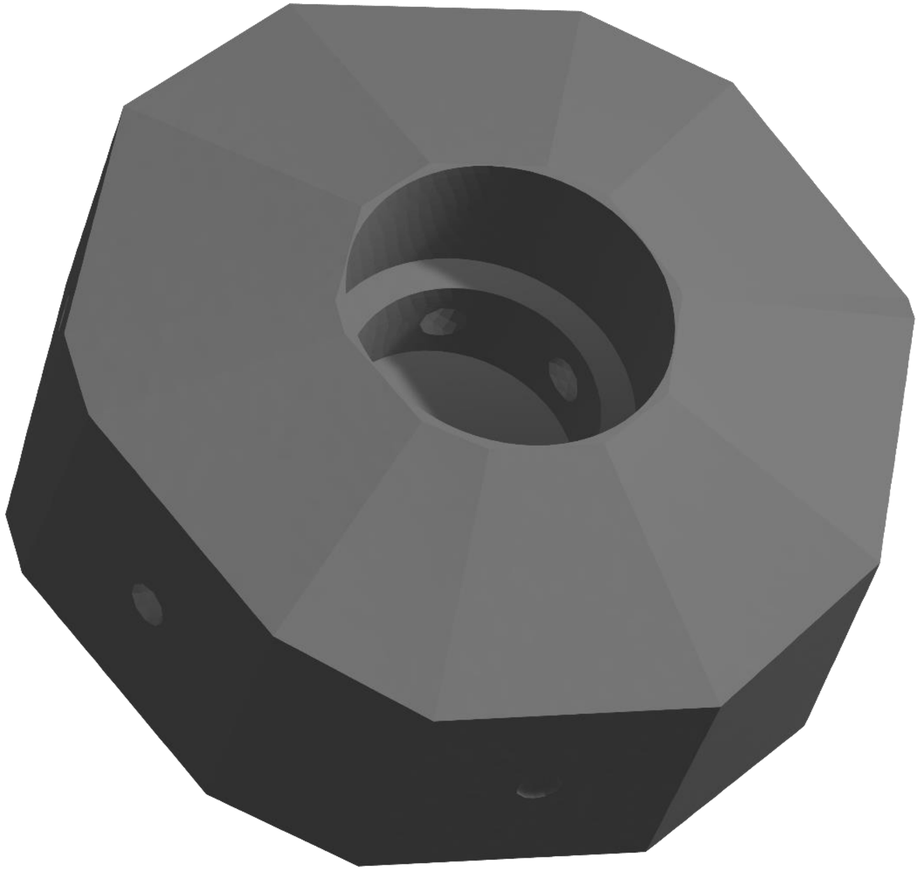
A	B	C	D	E
Formfinding force LC0 [N]				
1	-1076.49	-670.869	-1490.33	
2	649.9401	6.894196	2.128091	
3	-1720.09	1116.334	2789.226	
4	1269.18	658.9714	1649.398	
5	-566.163	-5.4849	-35.0467	
6	1443.604	-1105.53	-2347.43	
Formfinding moment LC0 [Nmm]				
1	-2183.86	4536.84	-4141.91	
2	-2135.31	2732.211	-480.445	
3	-1546.63	-1832.28	-1636.13	
4	3195.263	830.3057	-3122.66	
5	2600.111	-3244.91	2762.6	
6	70.42637	-3022.17	6618.537	
Analysis LC0 + LC1 + LC2 [N]				
1	-6895.08	-4235.39	-9372.89	
2	-2601.23	-44.058	-122.835	
3	347.3707	-325.695	-486.678	
4	7598.729	3829.858	9949.124	
5	1908.855	3.2648	57.30447	

Grasshopper output

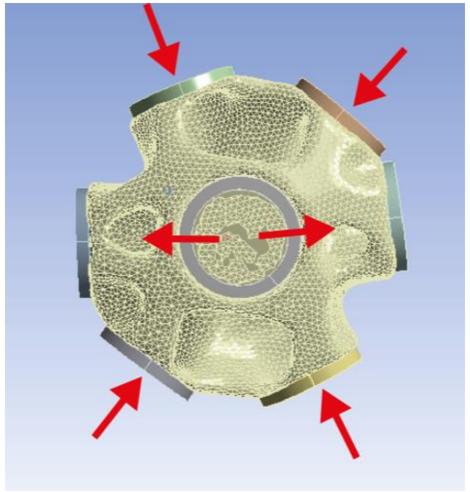


design evolution

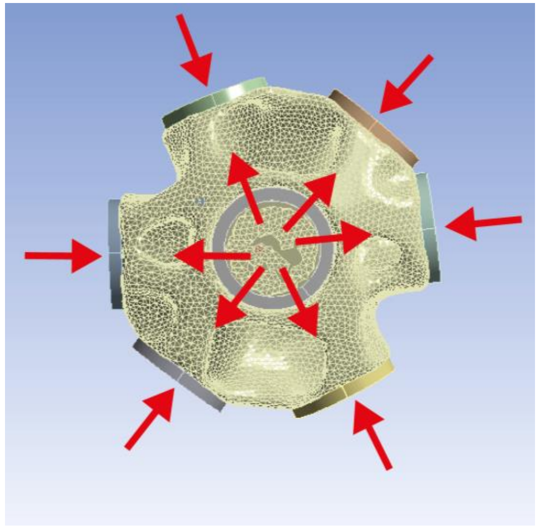
Diameter	140 mm
Mass goal	-
Section size limit	-
Mass	1.9 kg



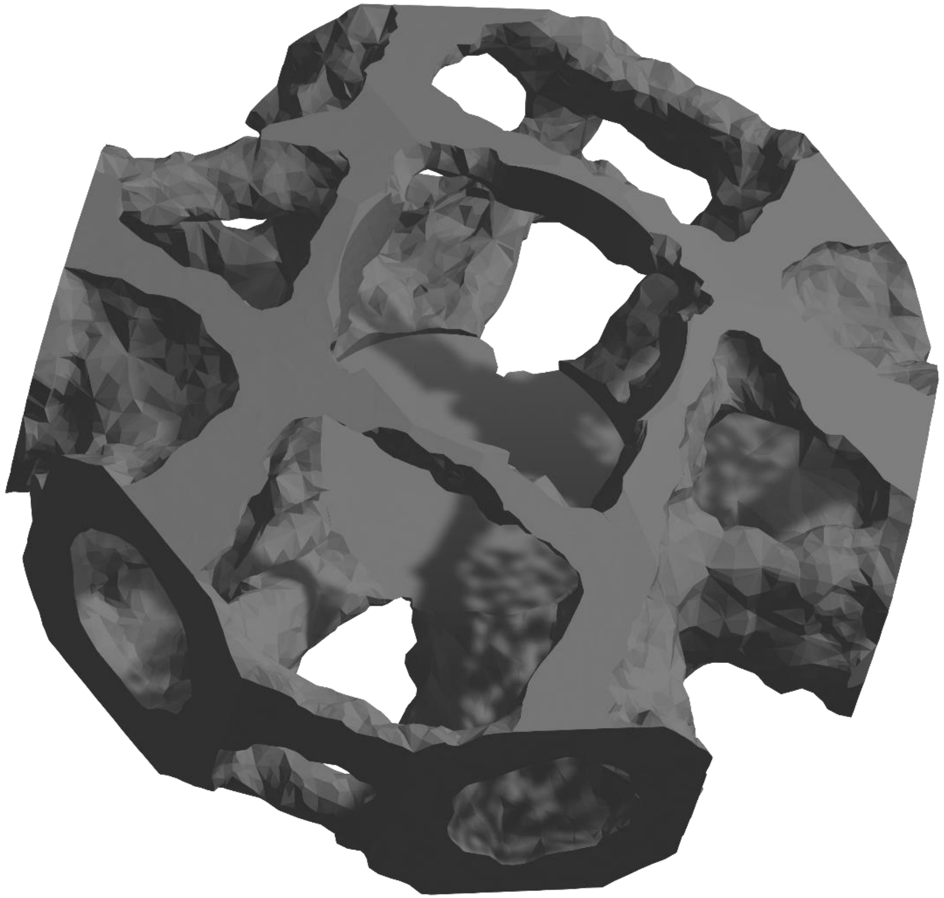
Diameter	140 mm
Mass goal	30%
Section size limit	-
Mass	0.61 kg



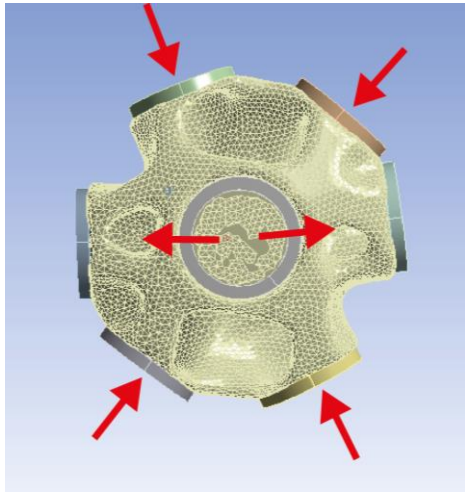
shell weight



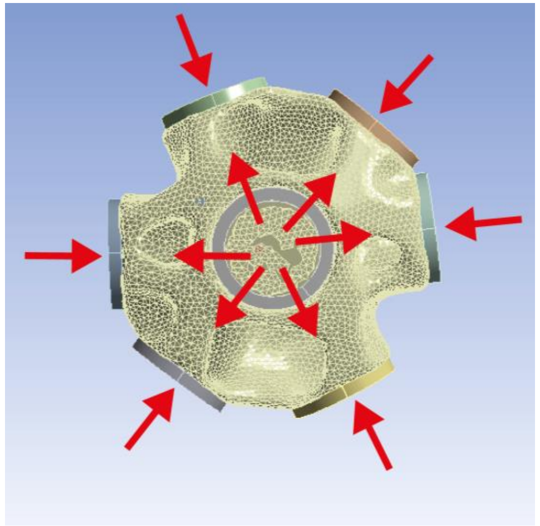
added load (1 kN)



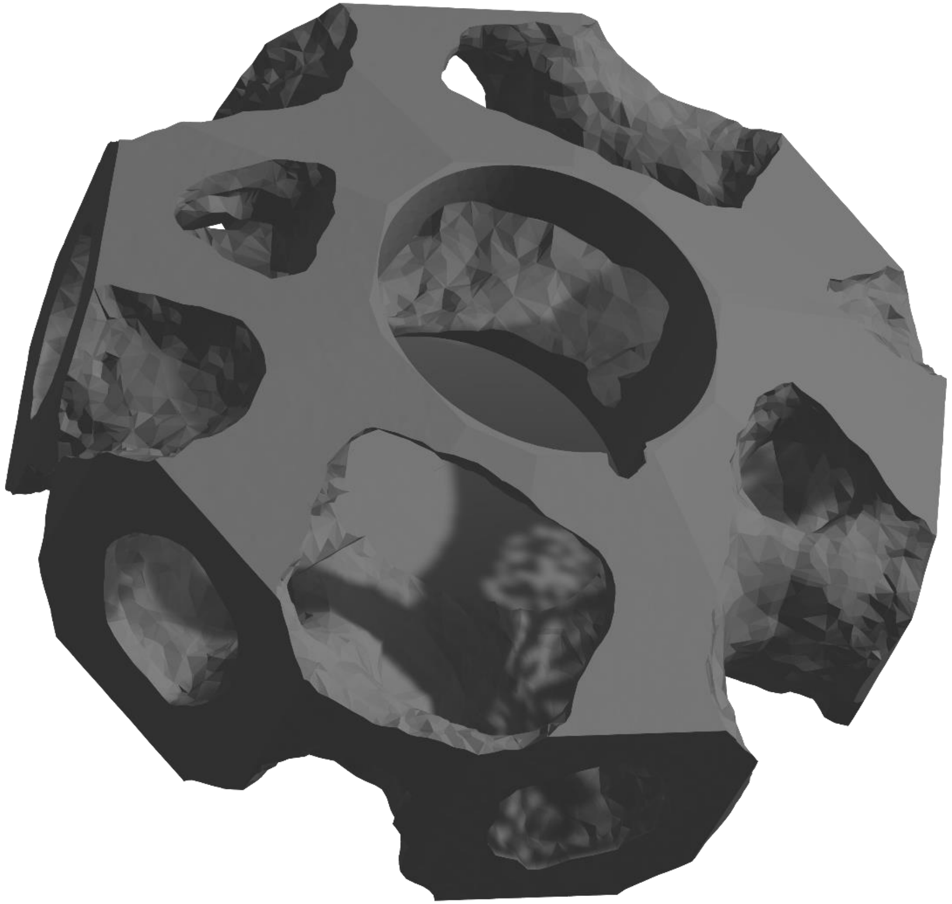
Diameter	140 mm
Mass goal	40%
Section size limit	20-50 mm
Mass	0.82 kg



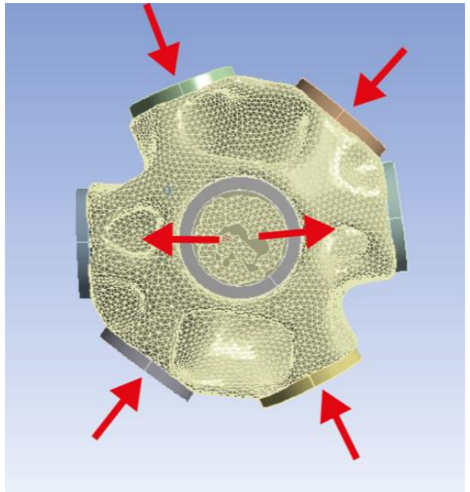
shell weight



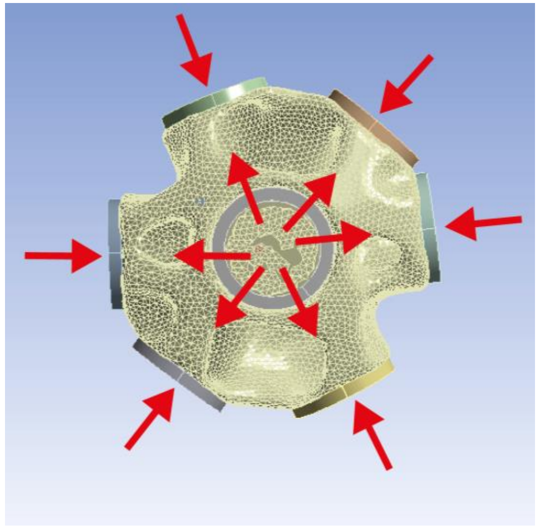
added load (1 kN)



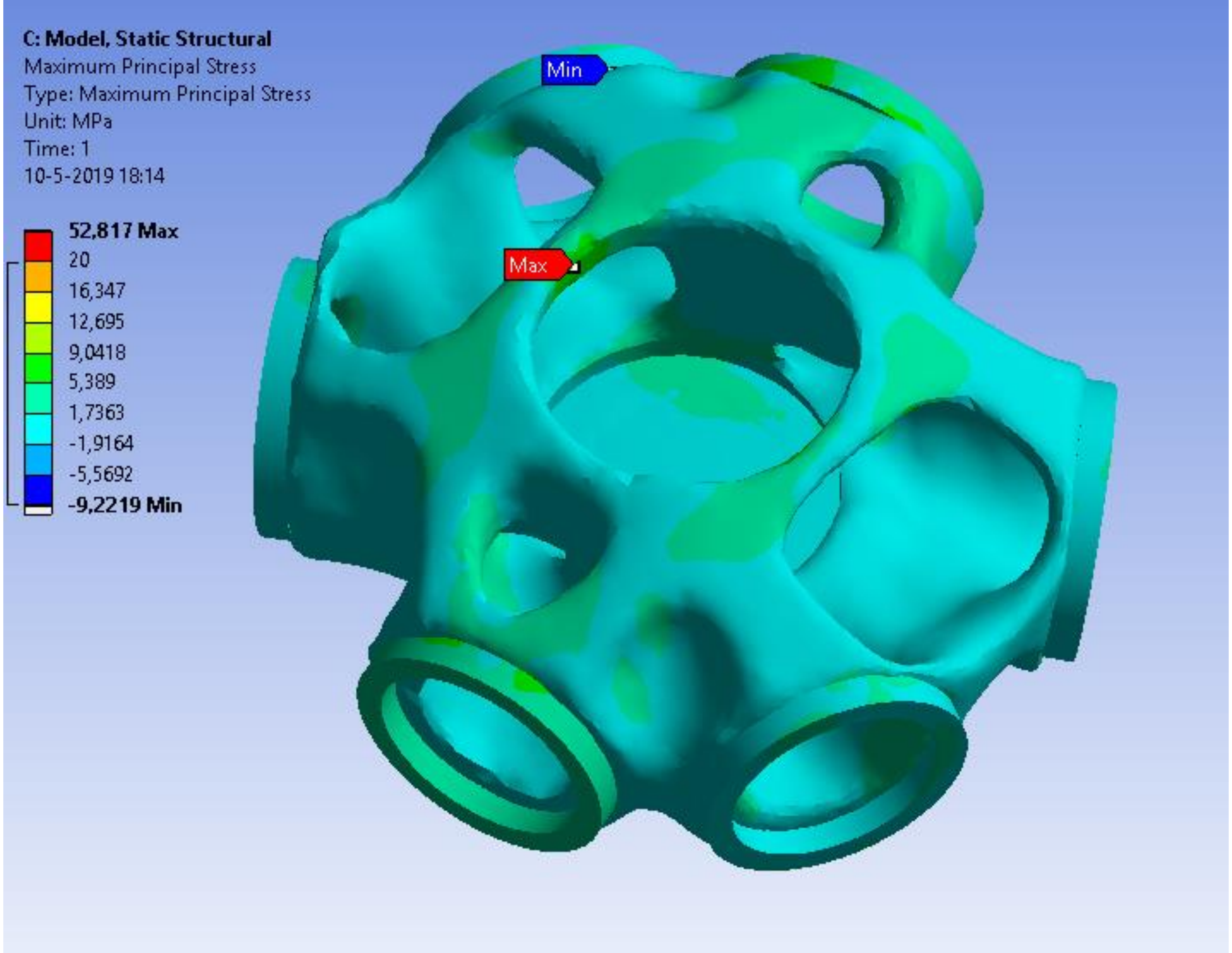
Diameter	140 mm
Mass goal	40%
Section size limit	20-50 mm
Mass	0.82 kg



shell weight

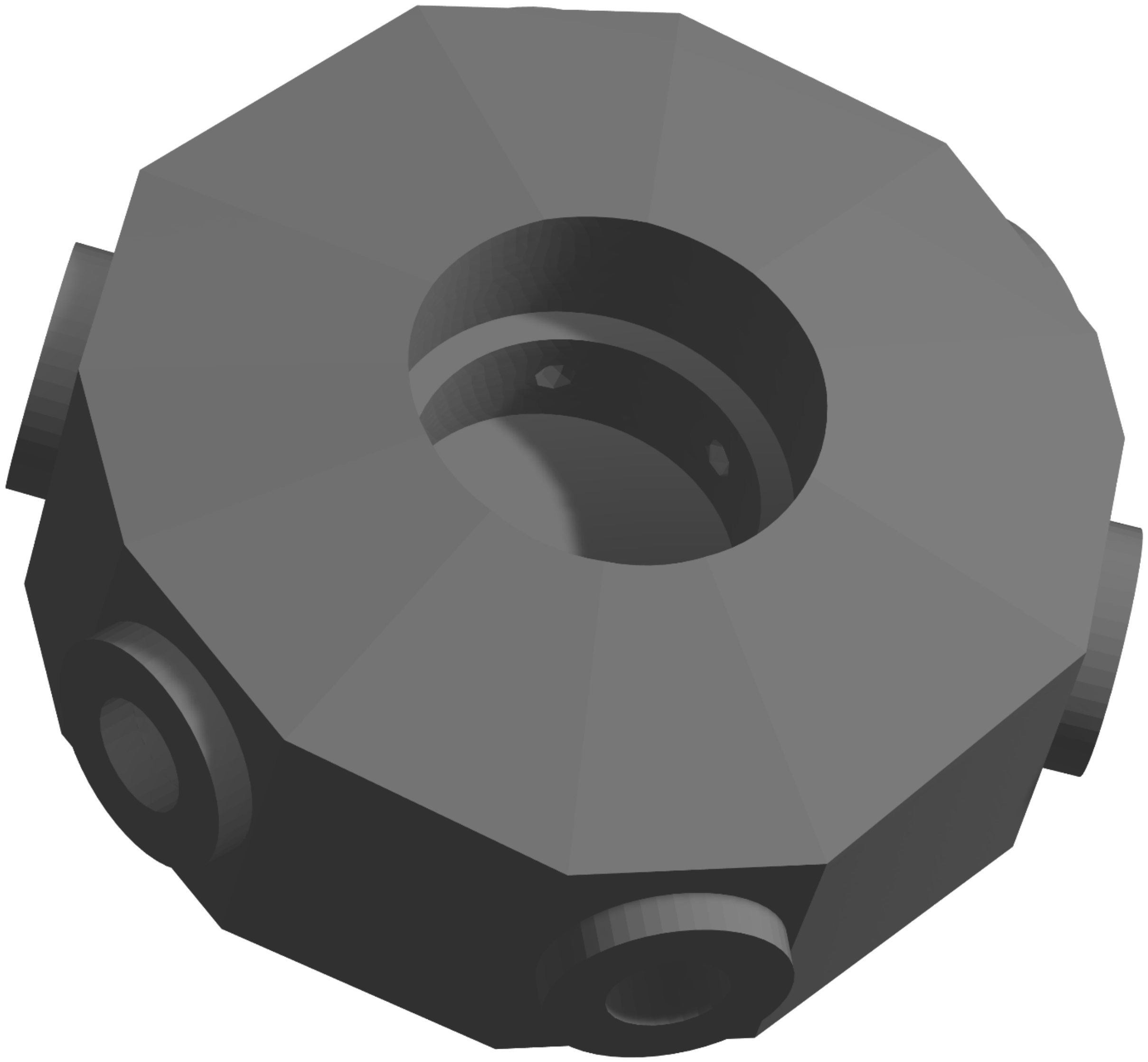


added load (1 kN)

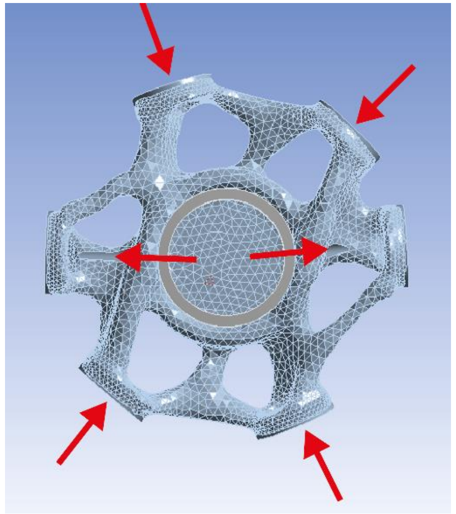

C: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
10-5-2019 18:14
52,817 Max
20
16,347
12,695
9,0418
5,389
1,7363
-1,9164
-5,5692
-9,2219 Min
Min
Max

Small node
structurally feasible
impractical to assemble
aesthetics

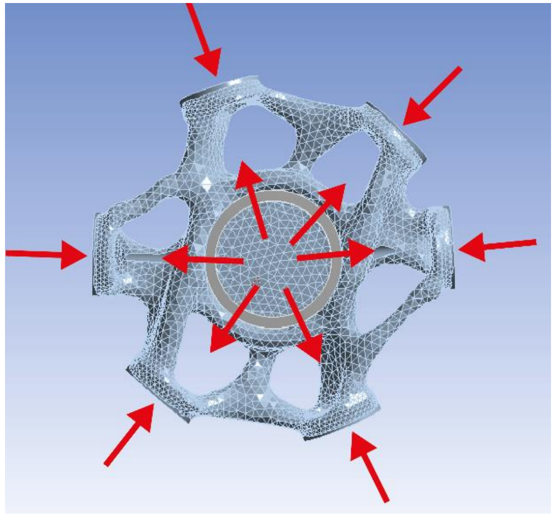
Diameter	240 mm
Mass goal	-
Section size limit	-
Mass	8.7 kg



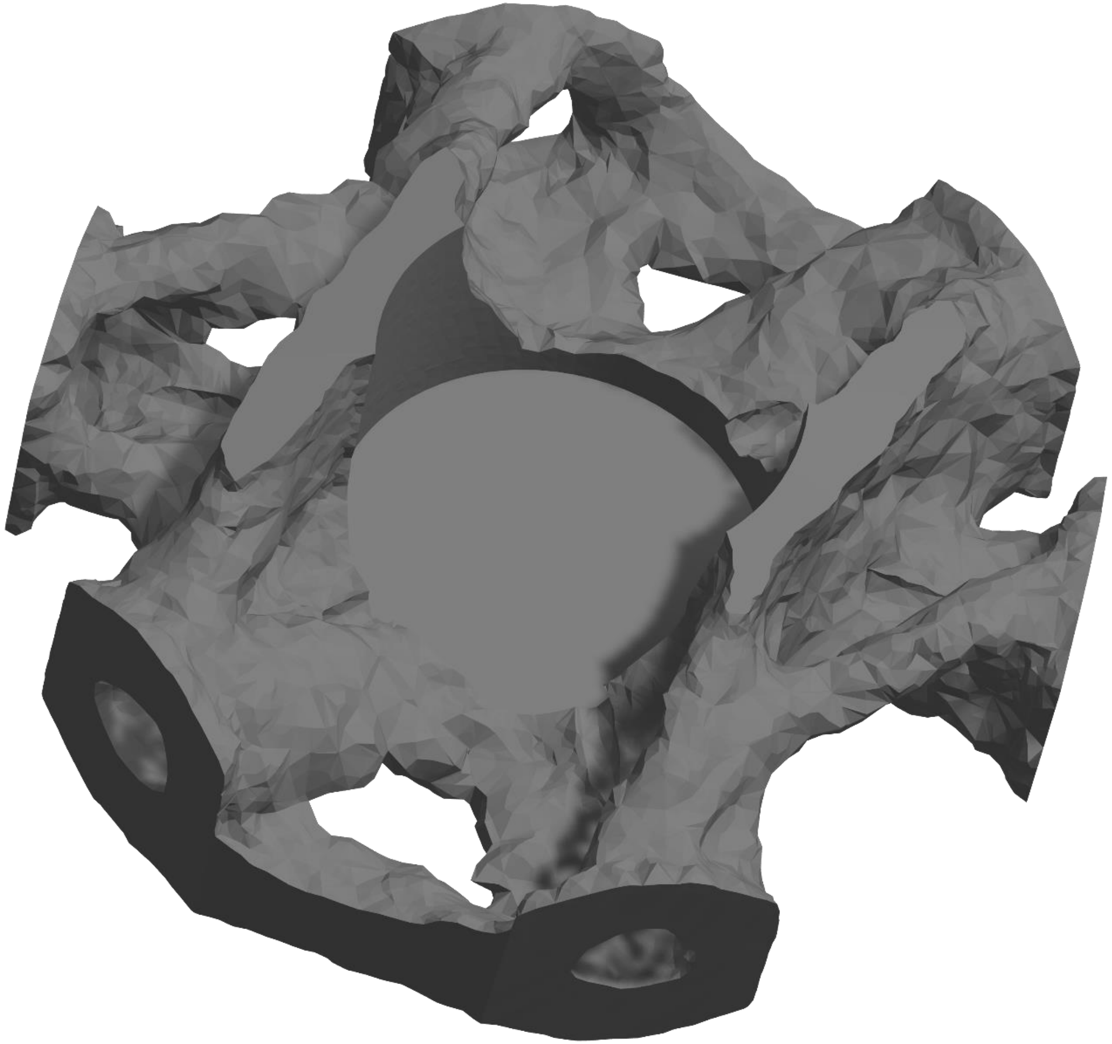
Diameter	240 mm
Mass goal	30%
Section size limit	30-50 mm
Mass	2.7 kg



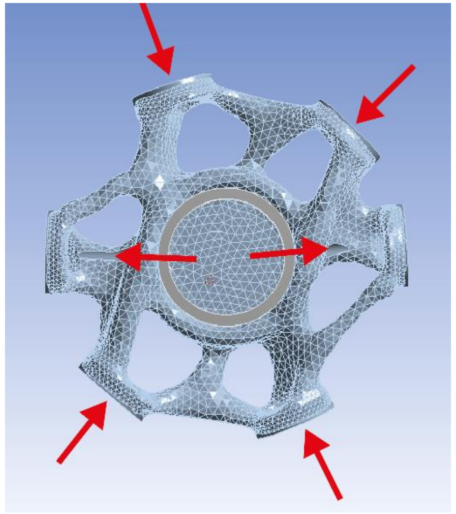
shell load



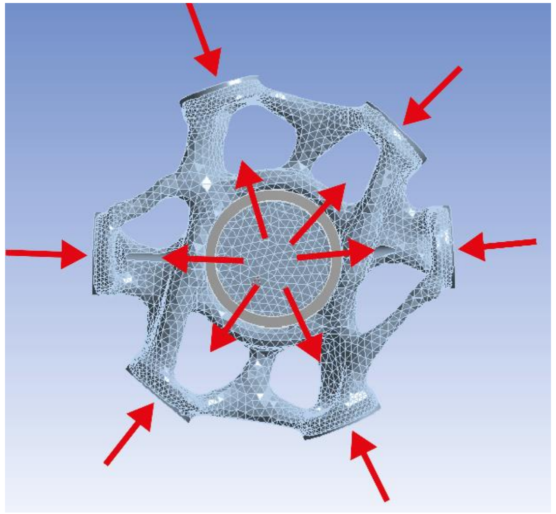
added load



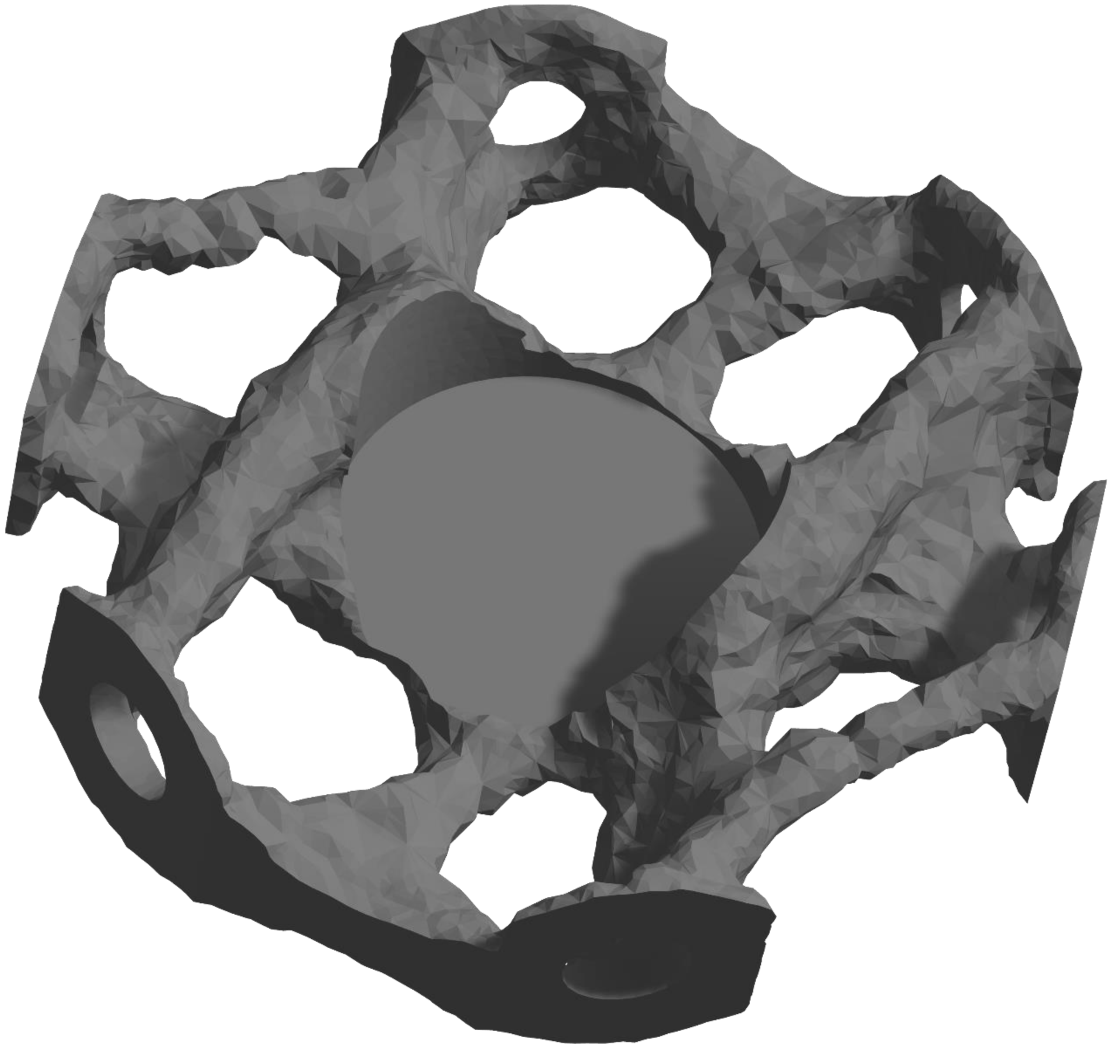
Diameter	240 mm
Mass goal	20%
Section size limit	30-50 mm
Mass	1.8 kg



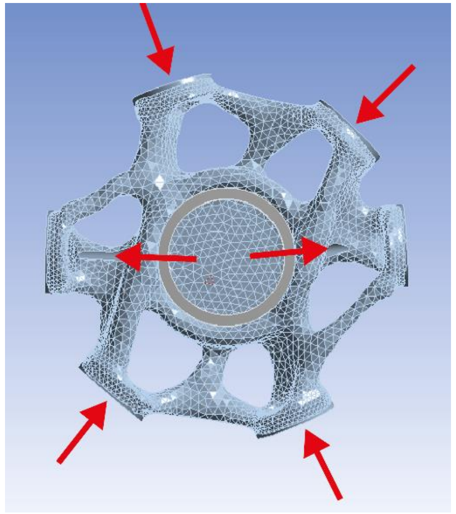
shell load



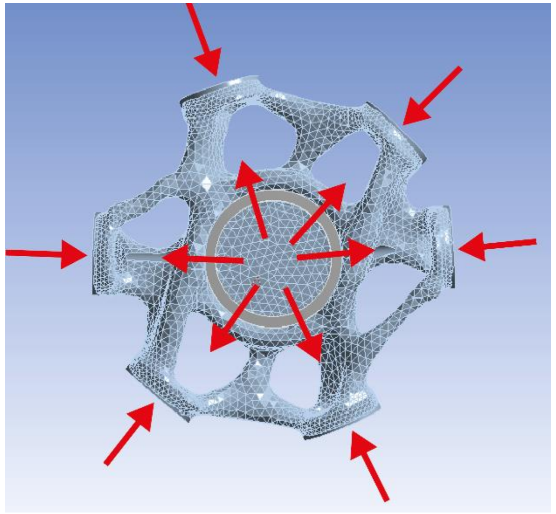
added load



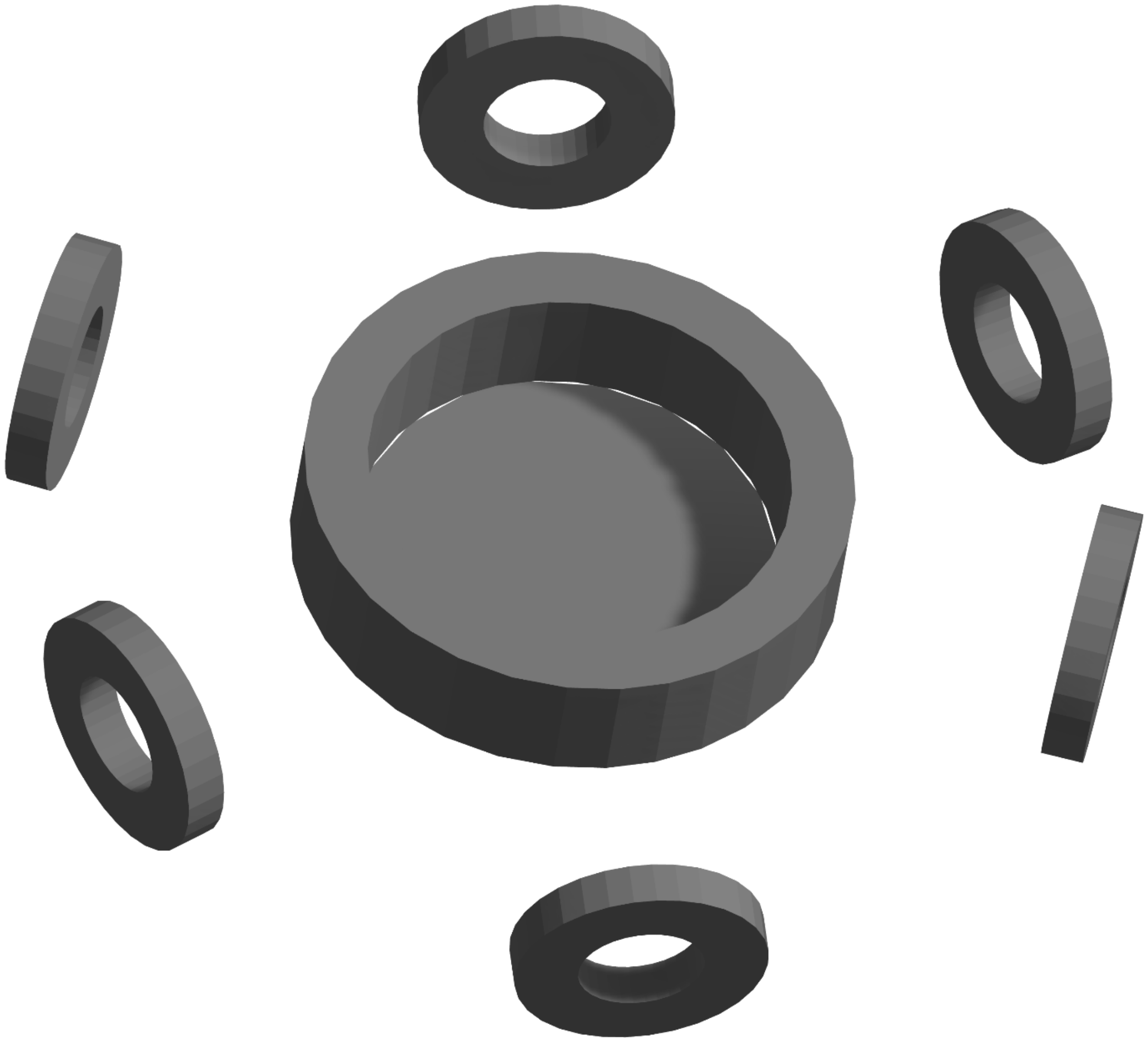
Diameter	240 mm
Mass goal	-
Section size limit	-
Mass	0.5 kg



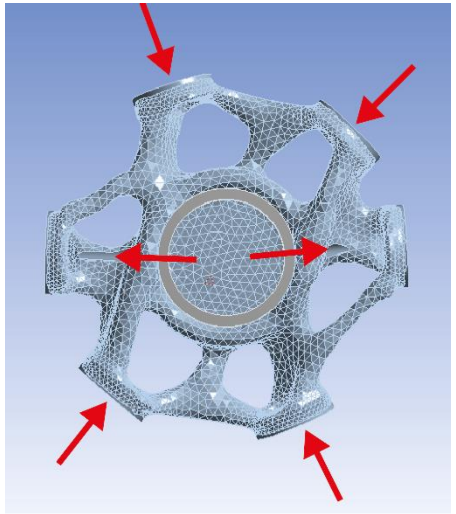
shell load



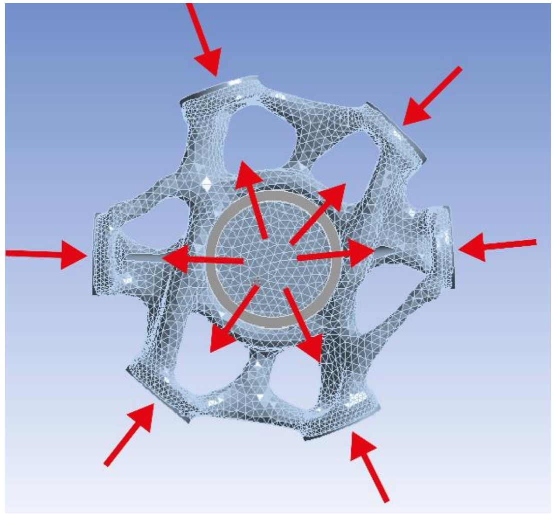
added load



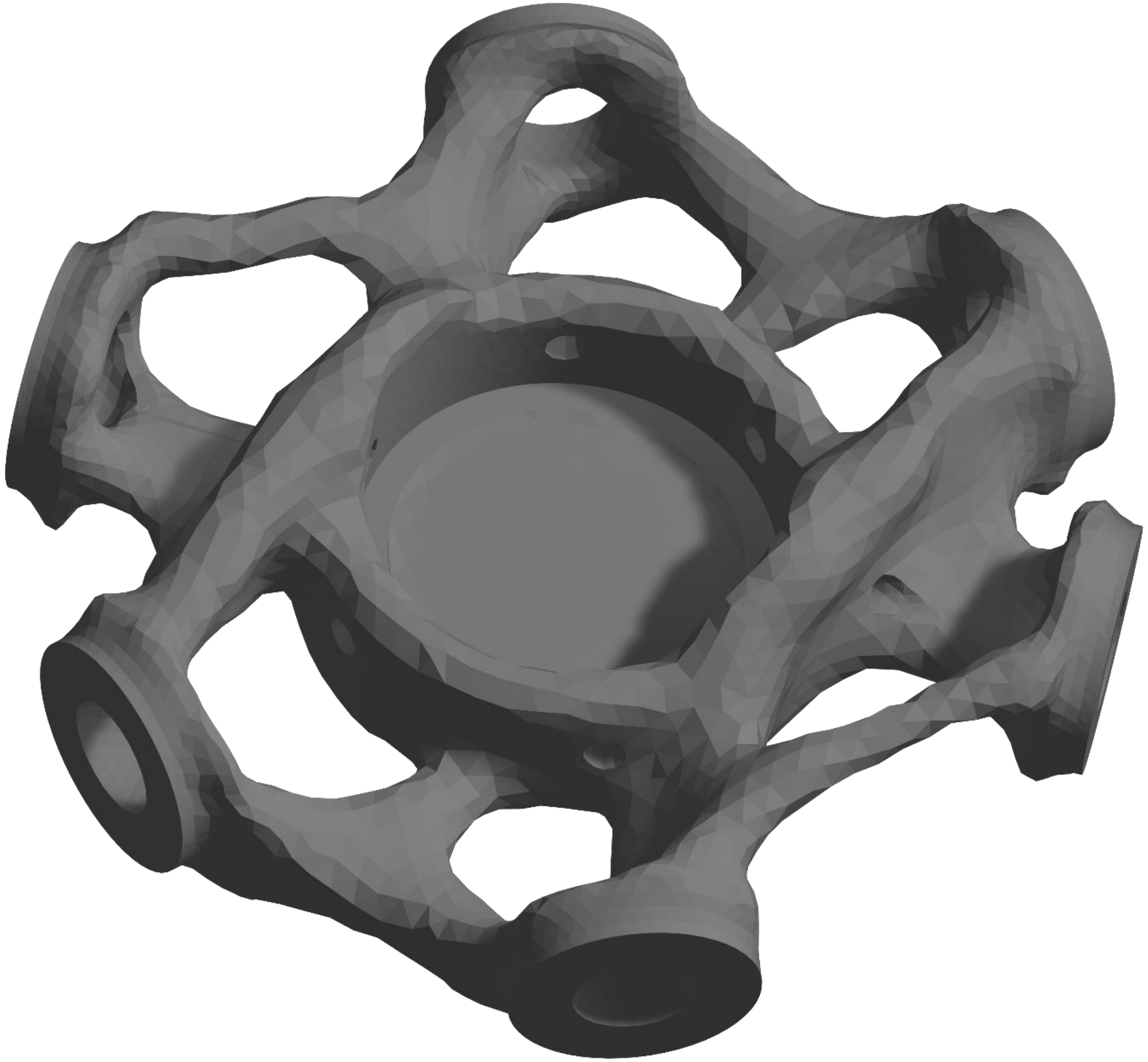
Diameter	240 mm
Mass goal	20%
Section size limit	30-50 mm
Mass	2.2 kg

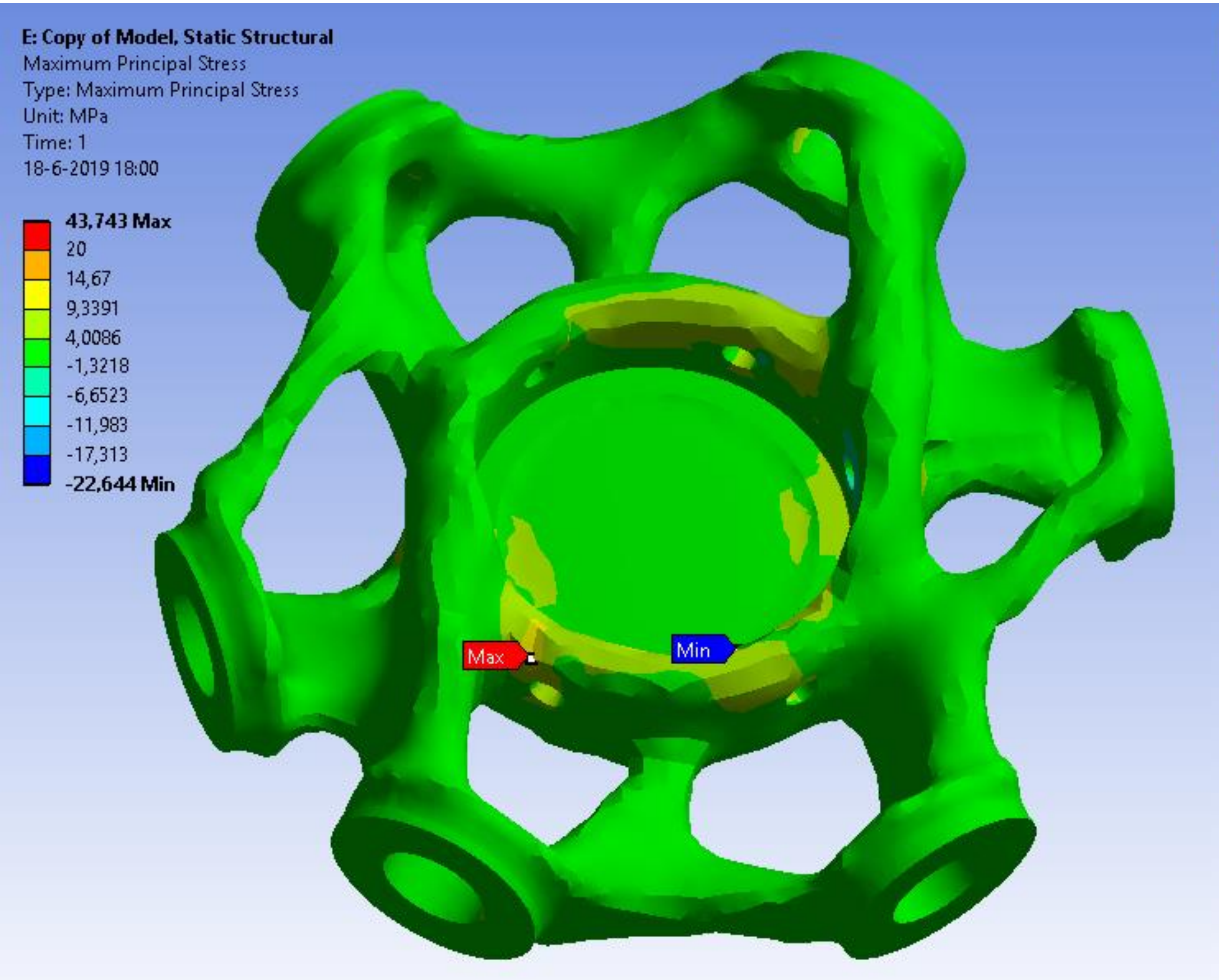


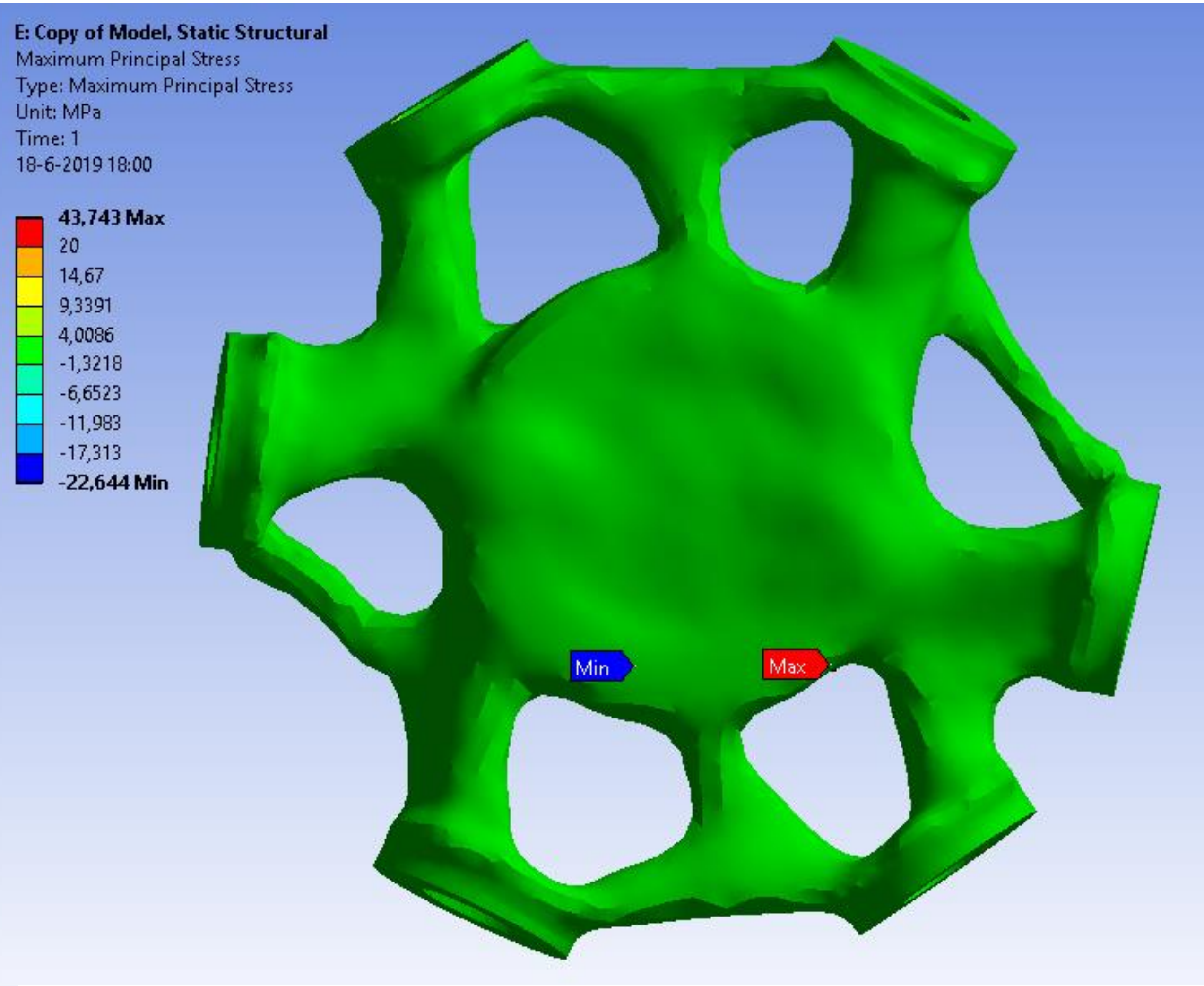
shell load



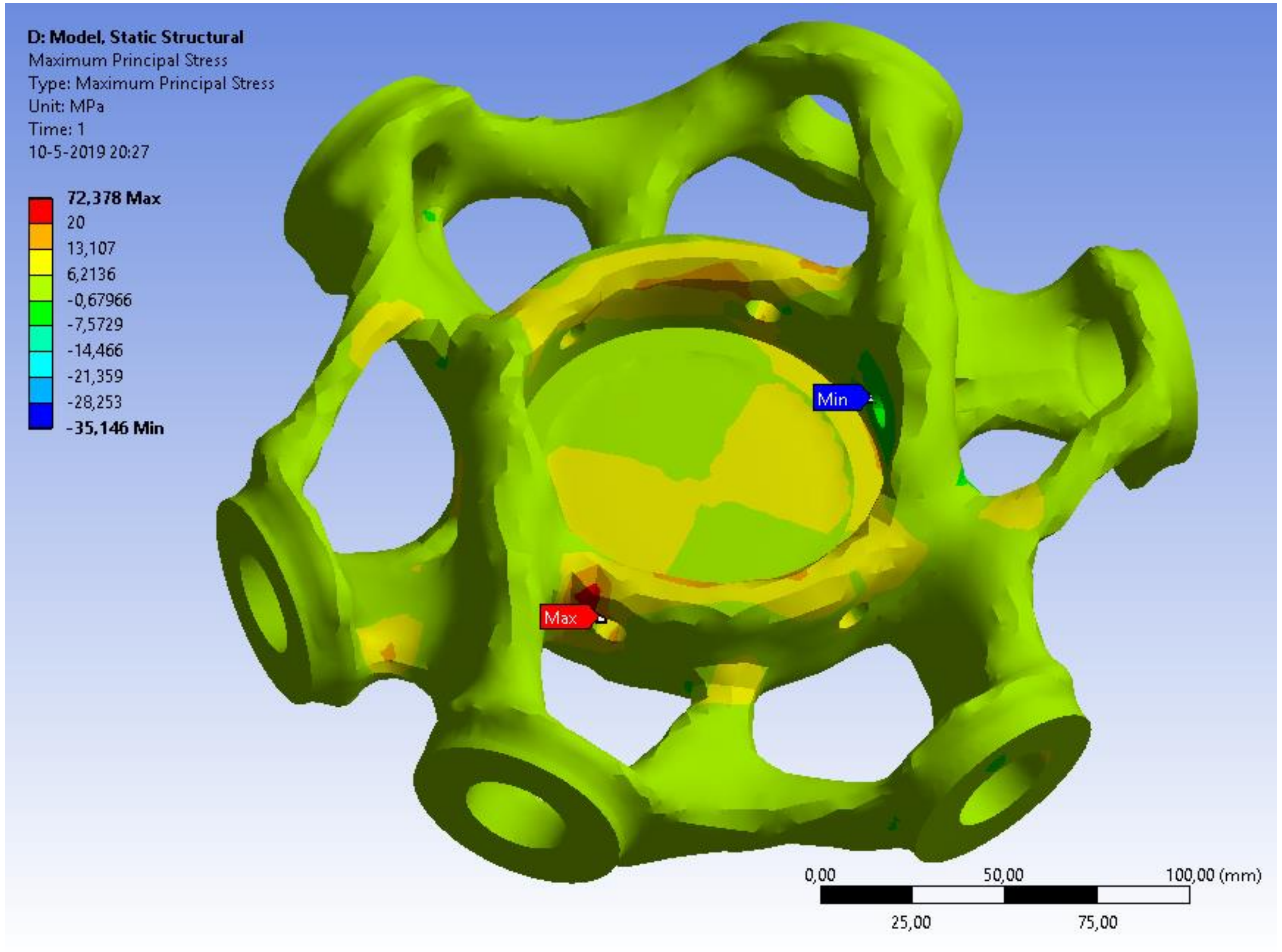
added load




E: Copy of Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
18-6-2019 18:00
43,743 Max
20
14,67
9,3391
4,0086
-1,3218
-6,6523
-11,983
-17,313
-22,644 Min
Max
Min


E: Copy of Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
18-6-2019 18:00
43,743 Max
20
14,67
9,3391
4,0086
-1,3218
-6,6523
-11,983
-17,313
-22,644 Min
Min
Max

stresses


D: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
10-5-2019 20:27
72,378 Max
20
13,107
6,2136
-0,67966
-7,5729
-14,466
-21,359
-28,253
-35,146 Min
Min
Max
0,00
50,00
100,00 (mm)
25,00
75,00

wind load

Topology optimisation

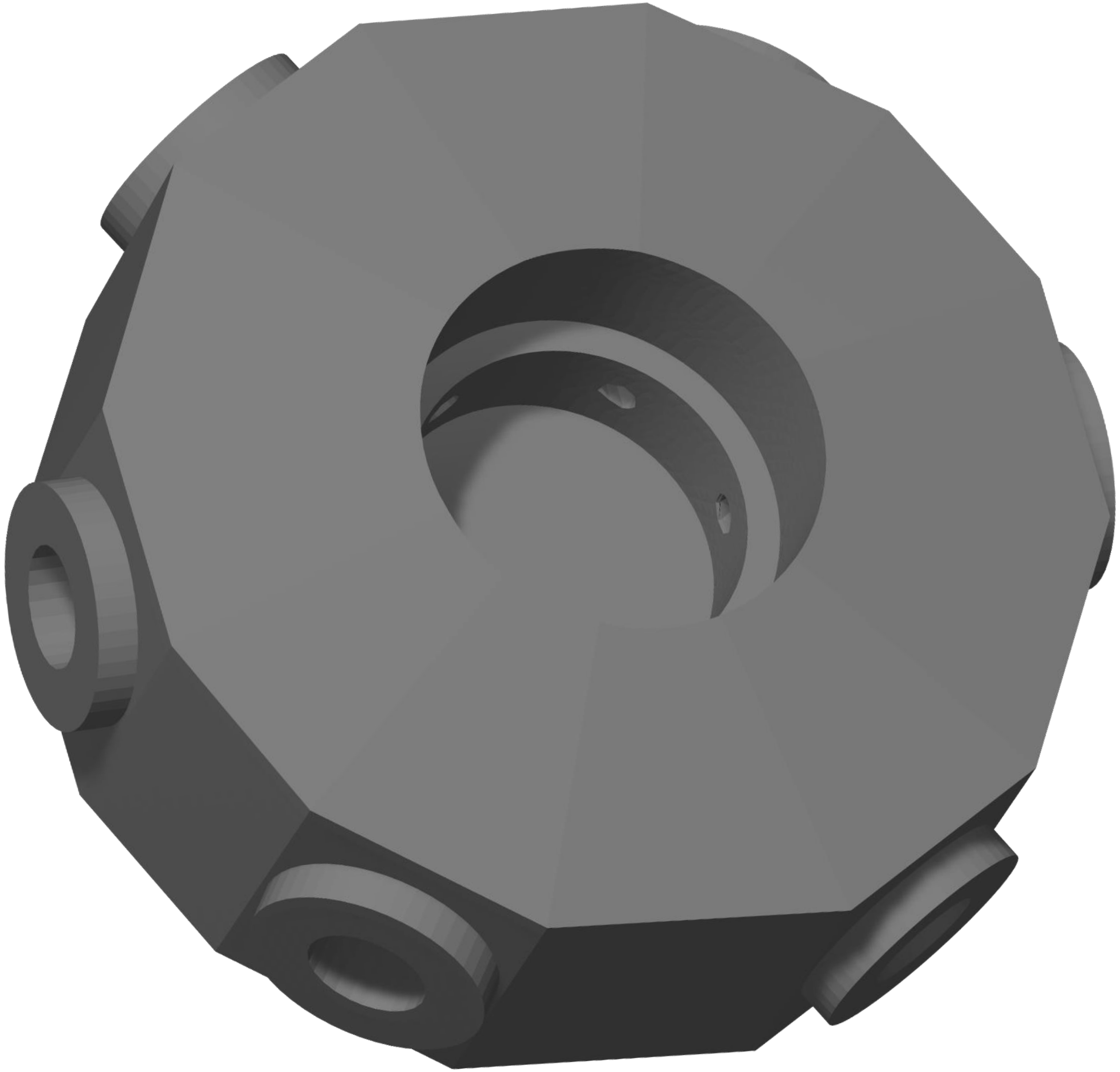
Efficient material distribution, for a specific loadcase

Dealing with changing loads

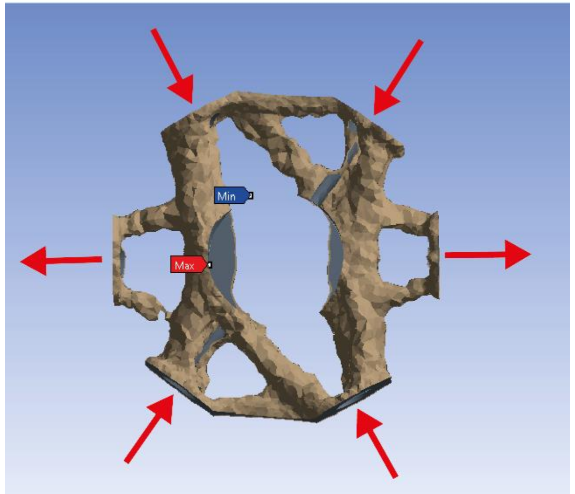
self load and external load

Topology optimisation
combined optimisation
increased mass

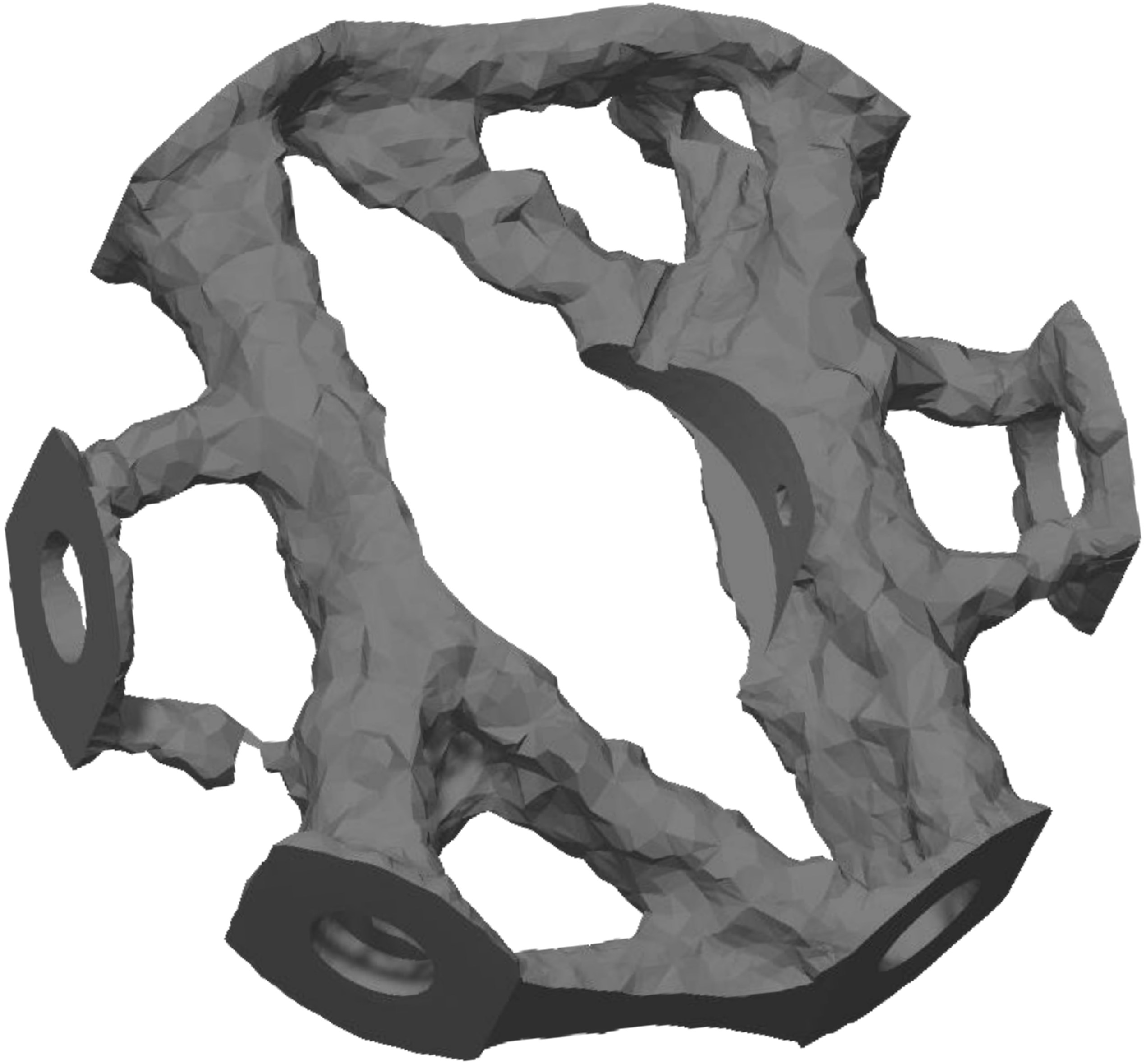
Diameter	240 mm
Mass goal	-
Section size limit	-
Mass	8.7 kg



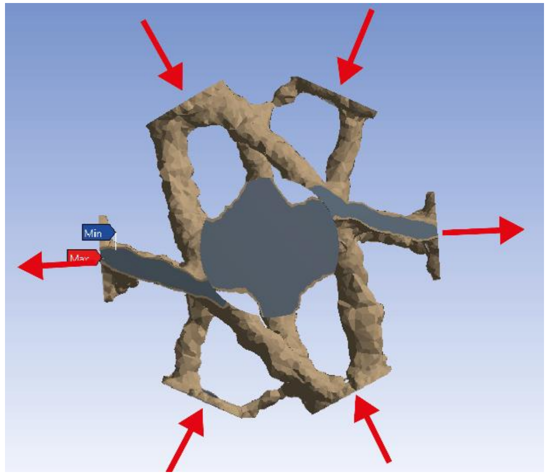
Diameter	240 mm
Mass goal	15%
Section size limit	20-50 mm
Mass	1.6 kg



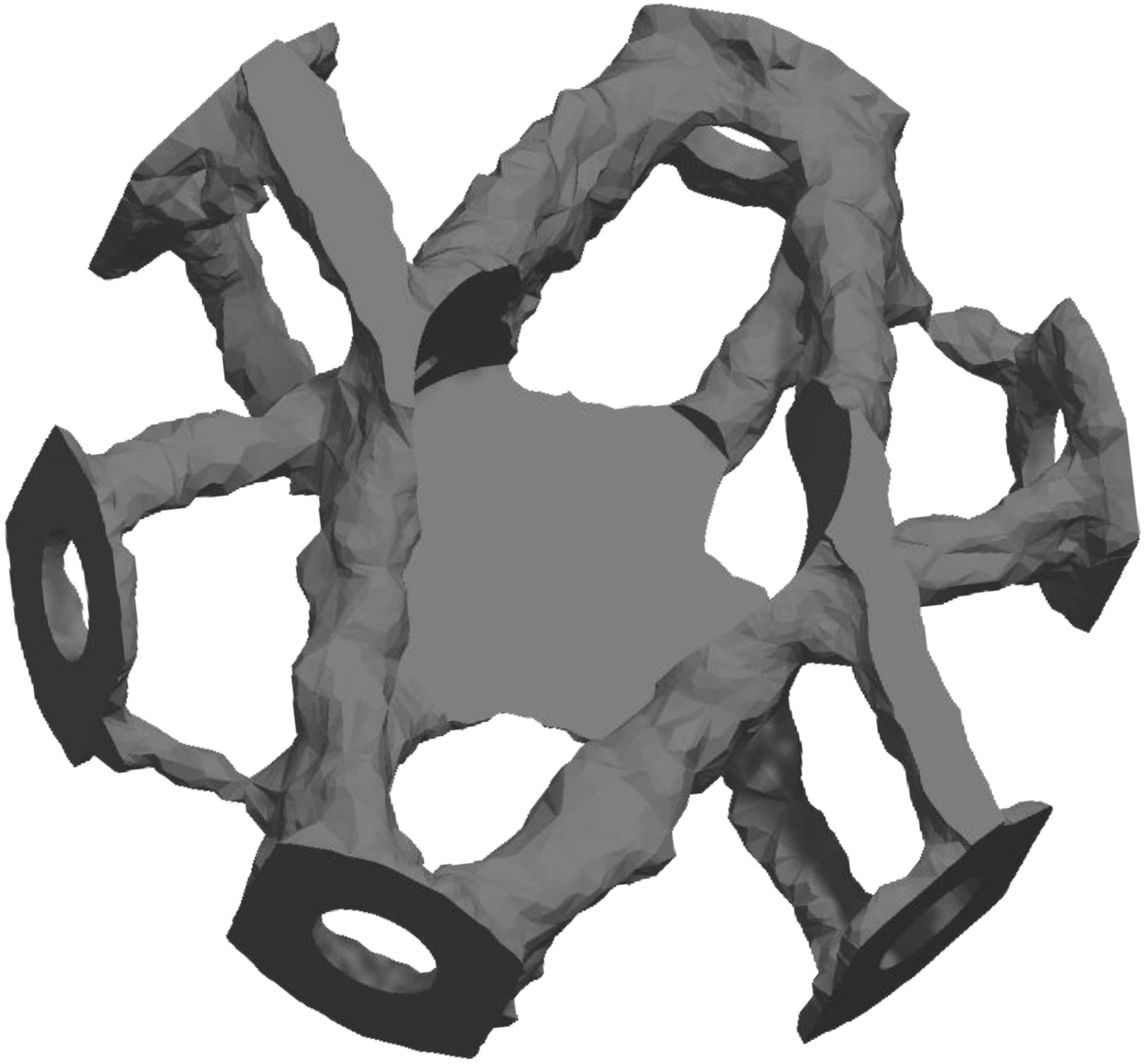
shell load



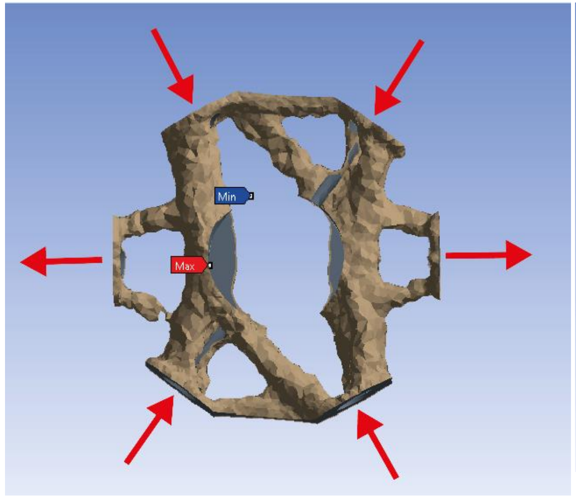
Diameter	240 mm
Mass goal	15%
Section size limit	20-50 mm
Mass	1.4 kg



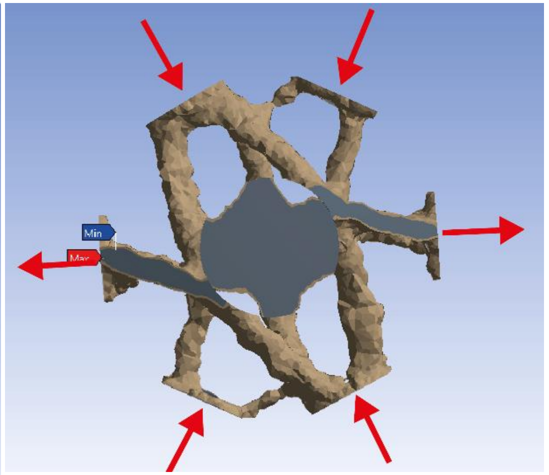
wind load



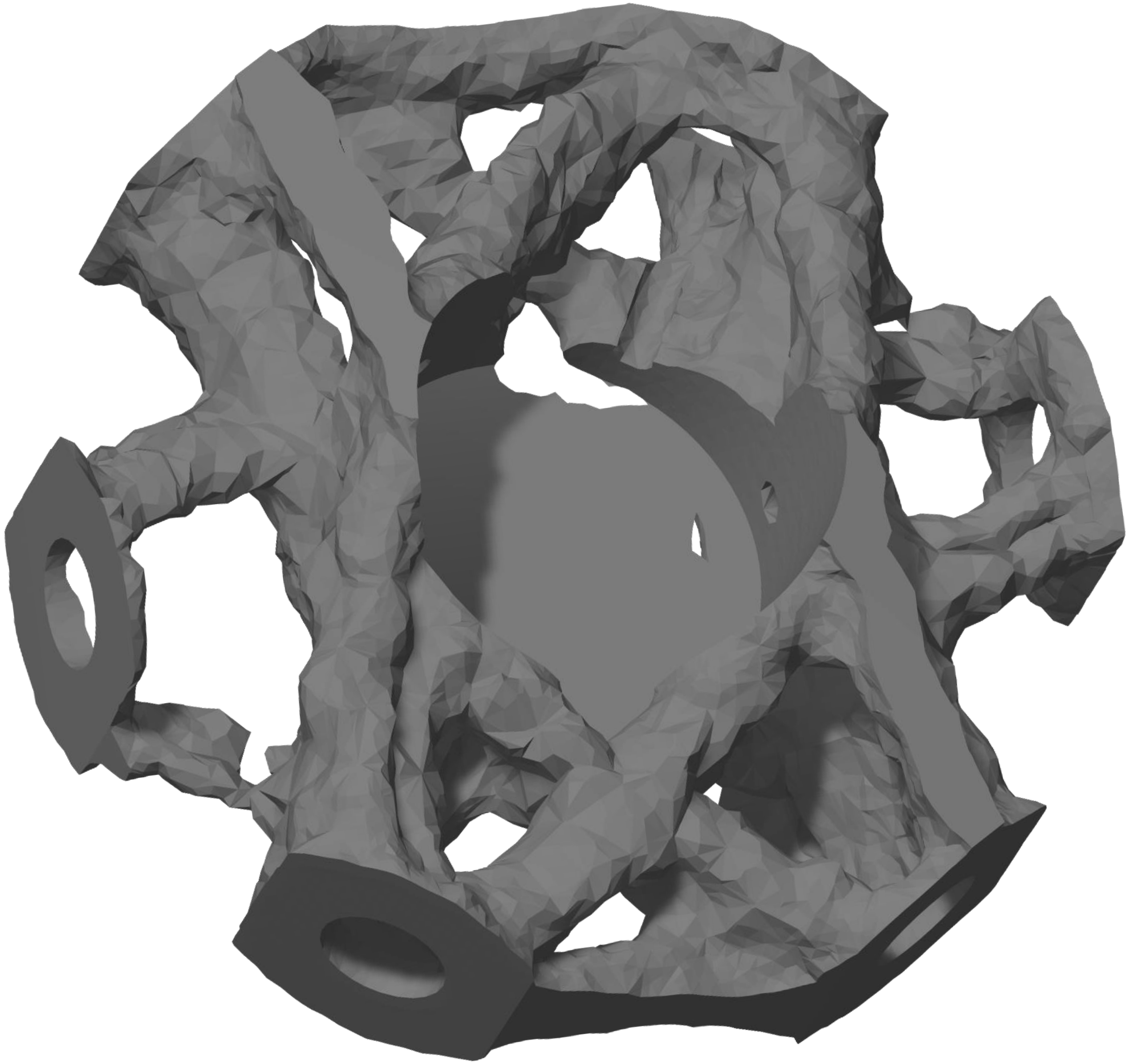
Diameter	240 mm
Mass goal	15%/15%
Section size limit	20-50 mm
Mass	2.4 kg



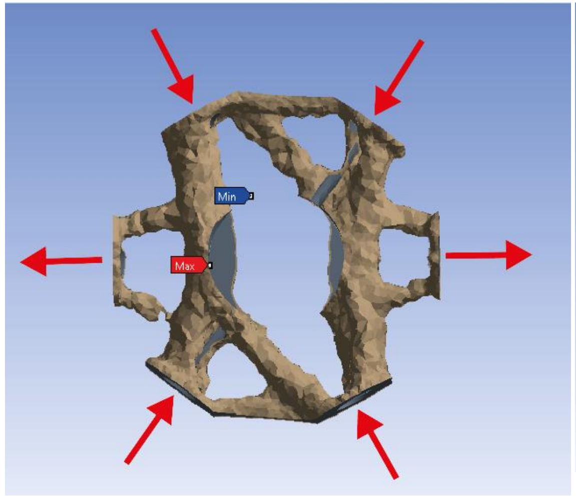
shell load



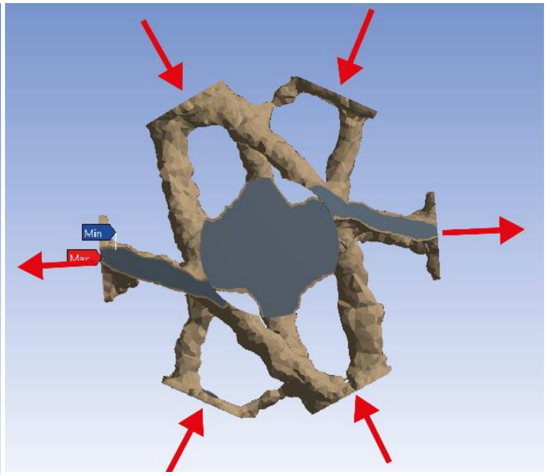
wind load



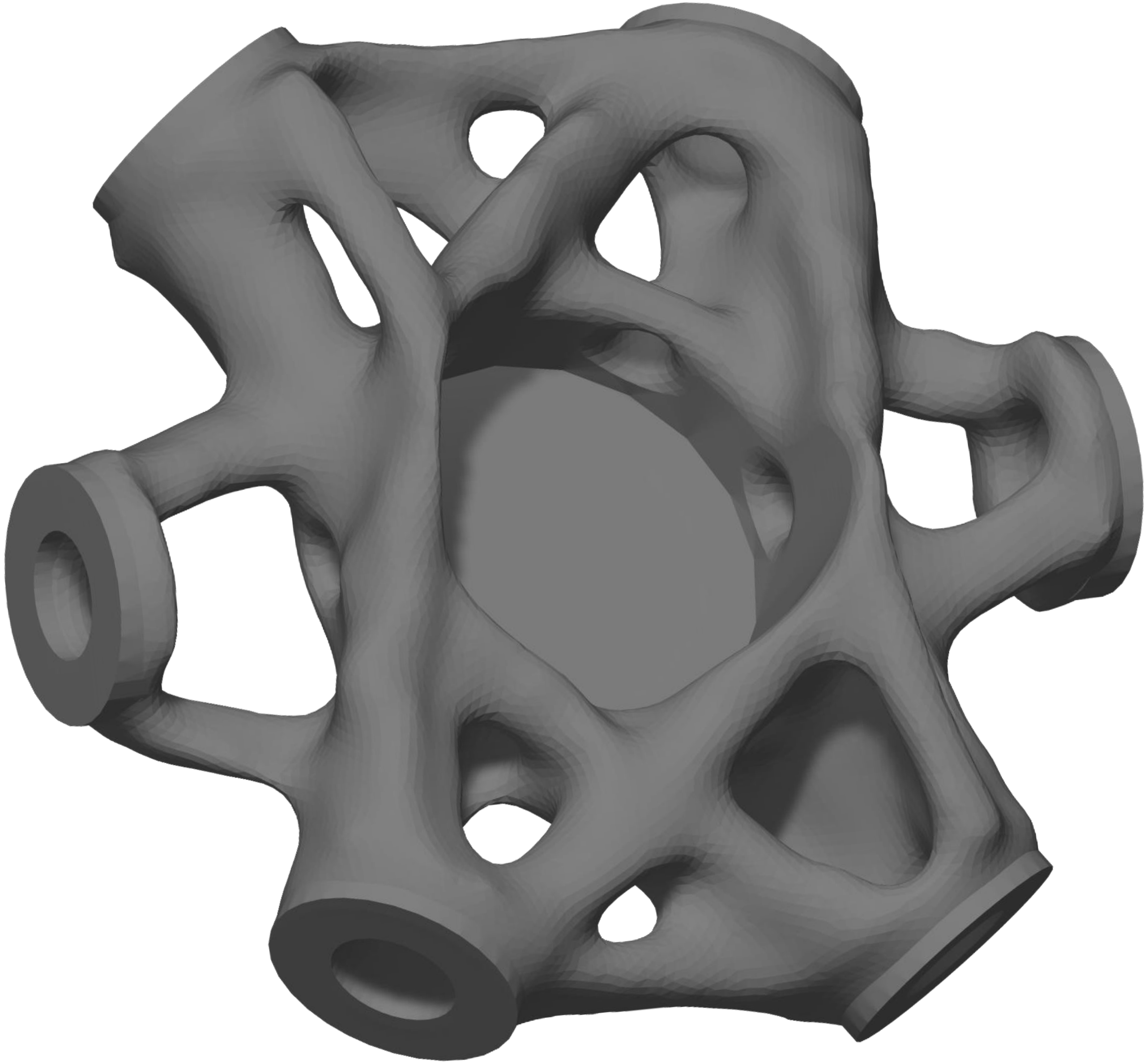
Diameter	240 mm
Mass goal	15%/15%
Section size limit	20-50 mm
Mass	2.7 kg

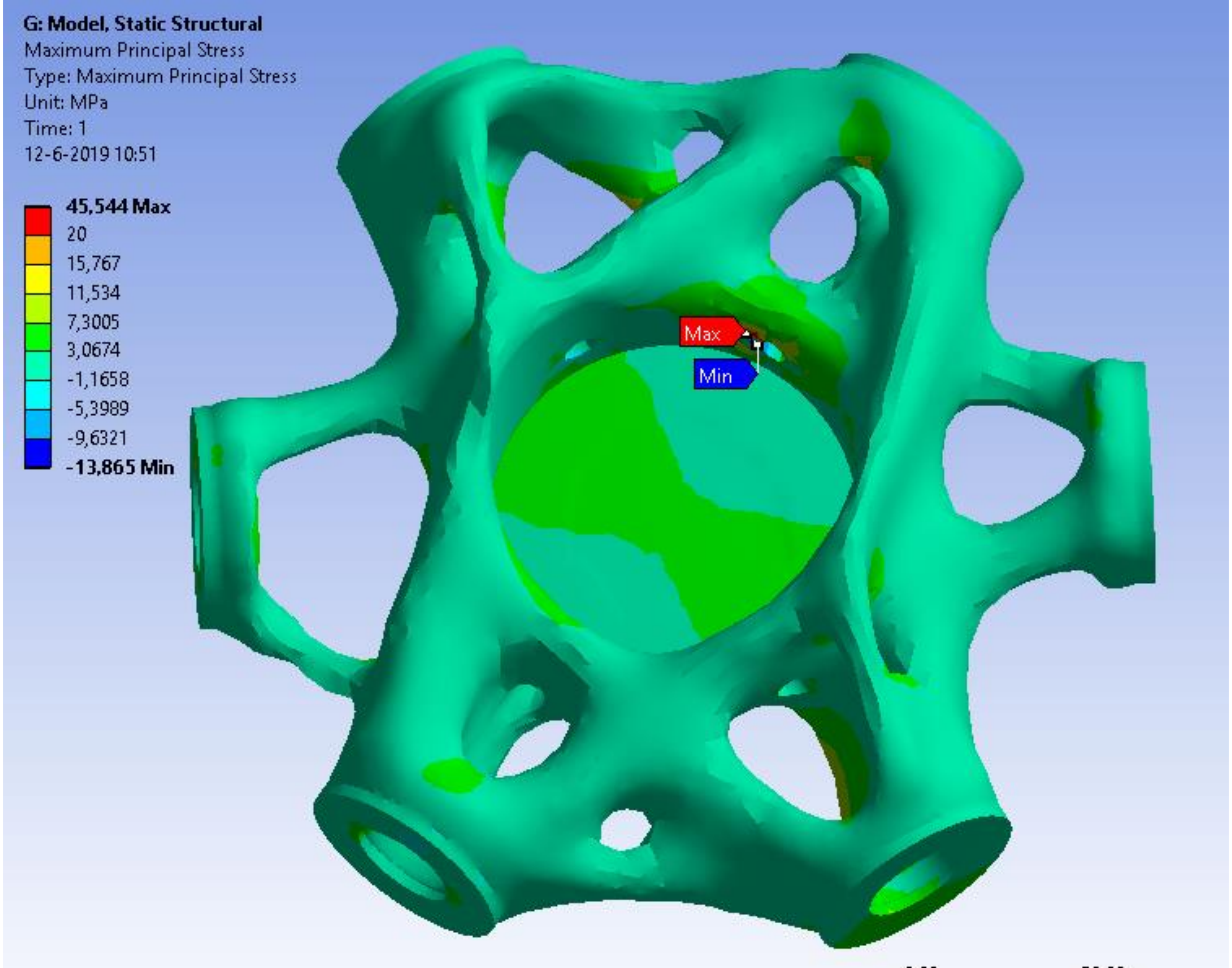


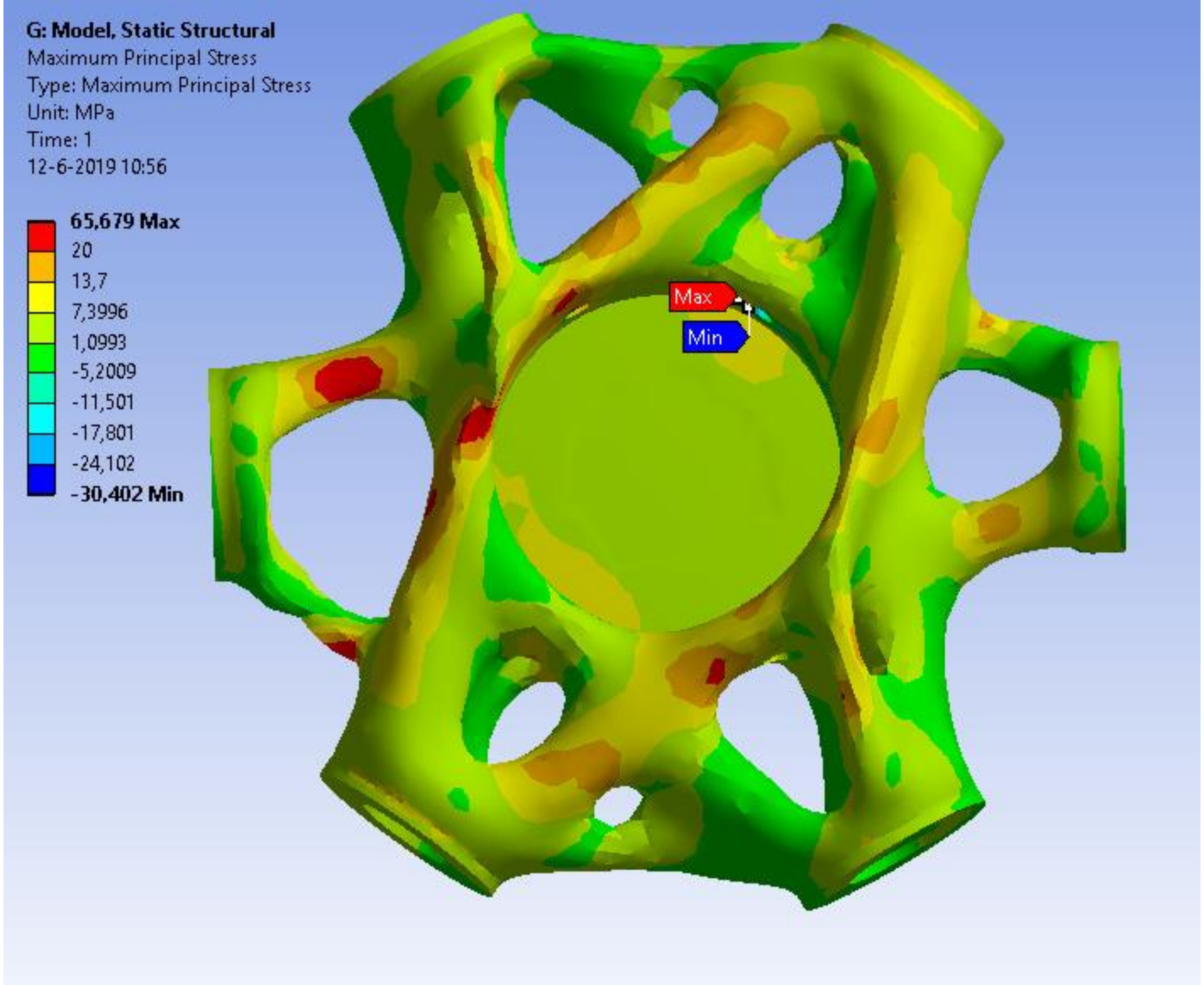
shell load



wind load

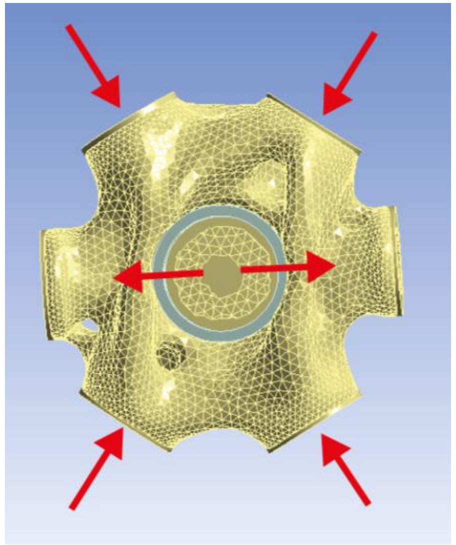



G: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
12-6-2019 10:51
45,544 Max
20
15,767
11,534
7,3005
3,0674
-1,1658
-5,3989
-9,6321
-13,865 Min
Max
Min

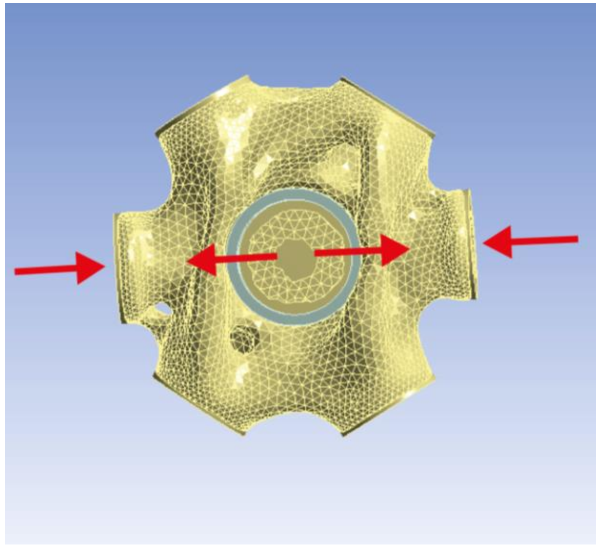

G: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
12-6-2019 10:56
65,679 Max
20
13,7
7,3996
1,0993
-5,2009
-11,501
-17,801
-24,102
-30,402 Min
Max
Min

Diameter	240 mm
Mass goal	-
Section size limit	-
Mass	10.8 kg

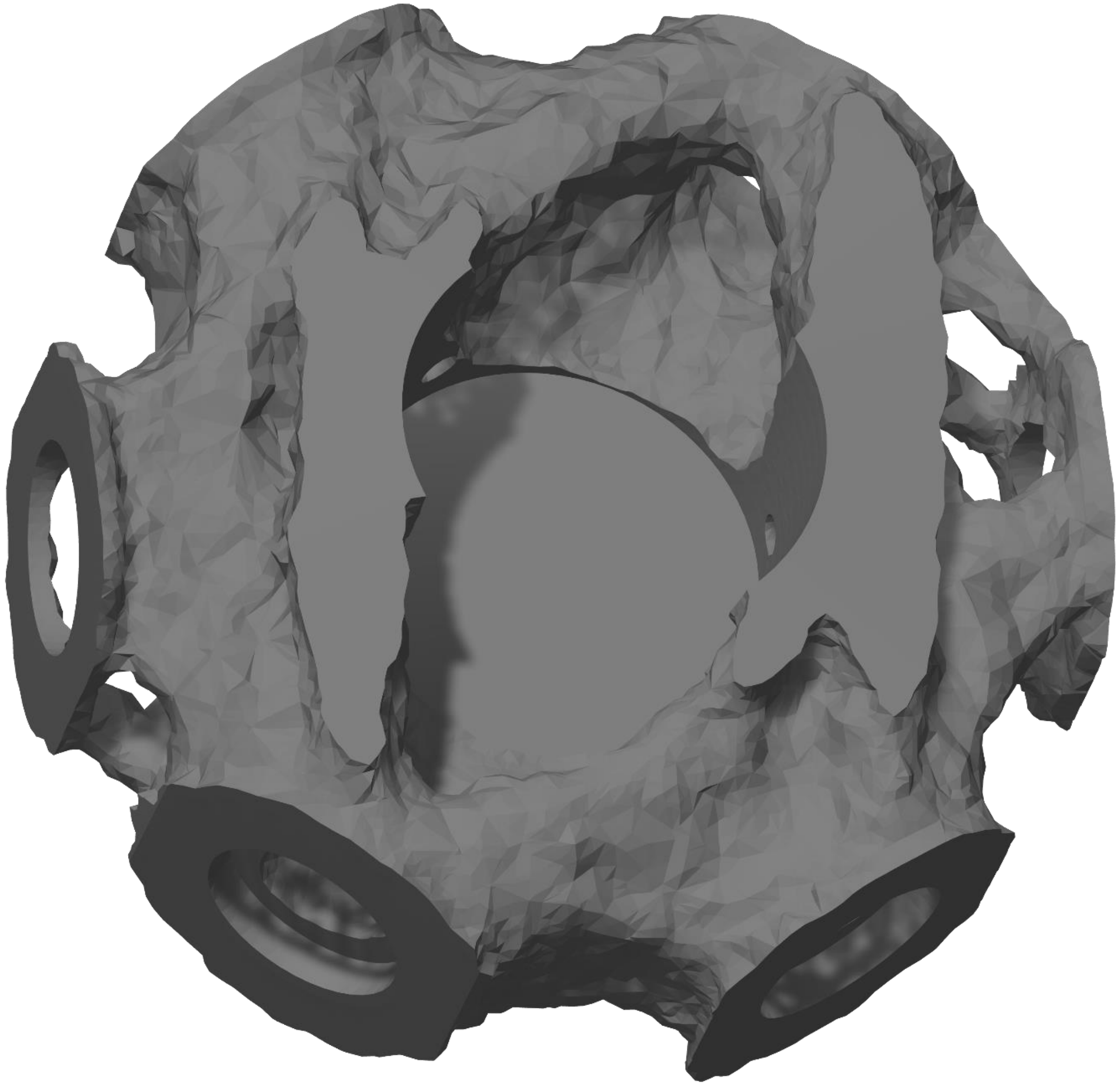
Diameter	240 mm
Mass goal	37%
Section size limit	20-40 mm
Mass	4.2 kg



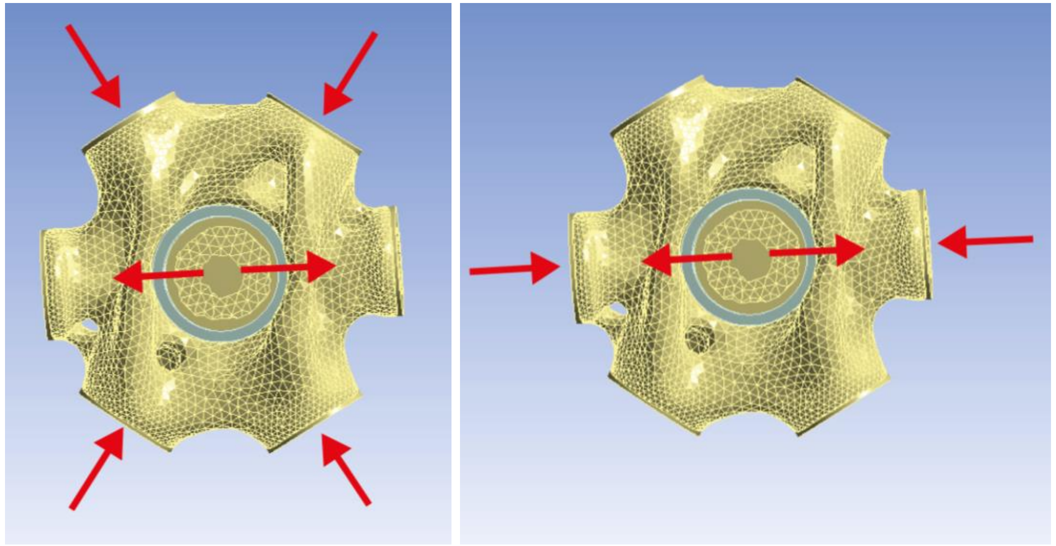
shell load



added load

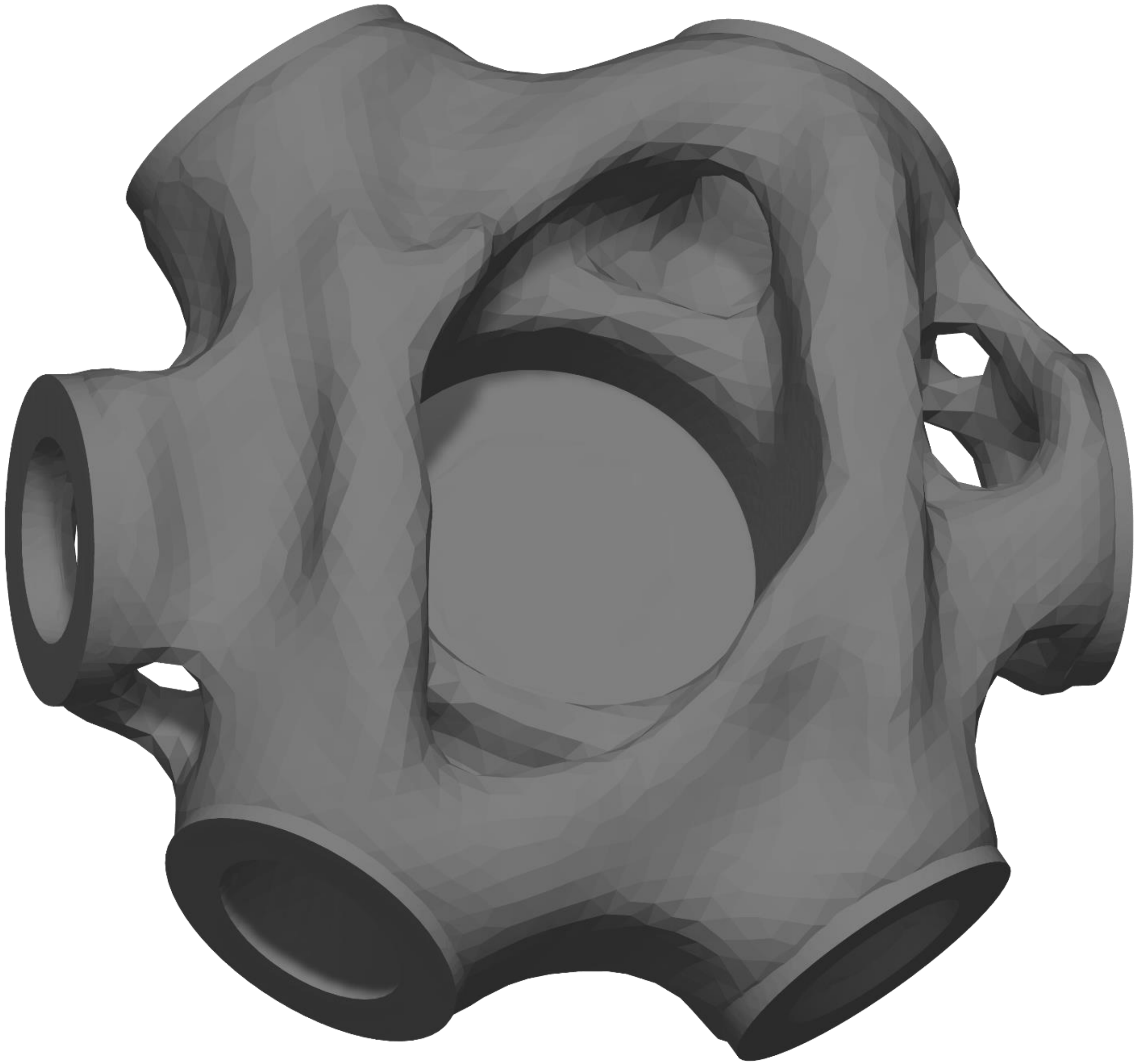


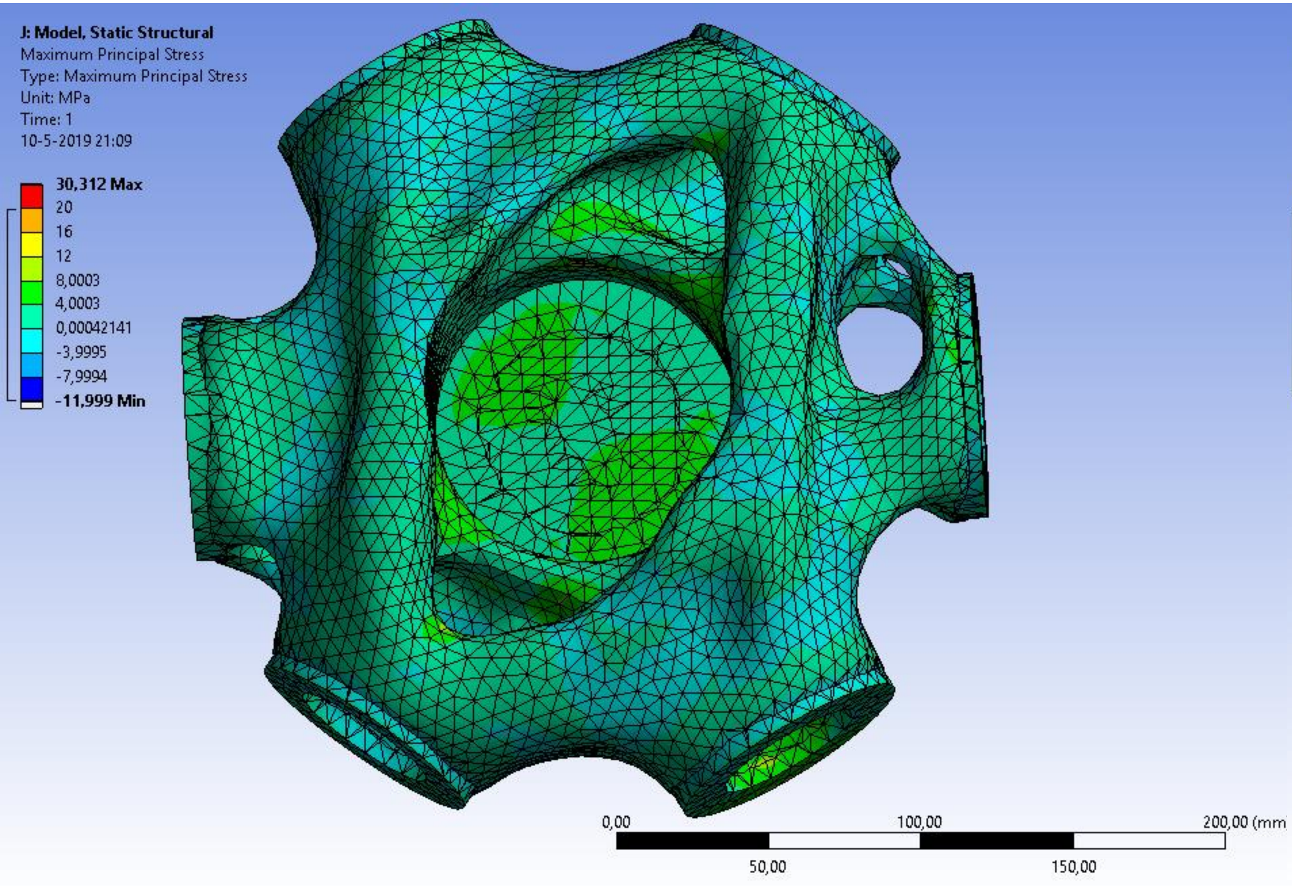
Diameter	240 mm
Mass goal	37%
Section size limit	20-40 mm
Mass	5.1 kg

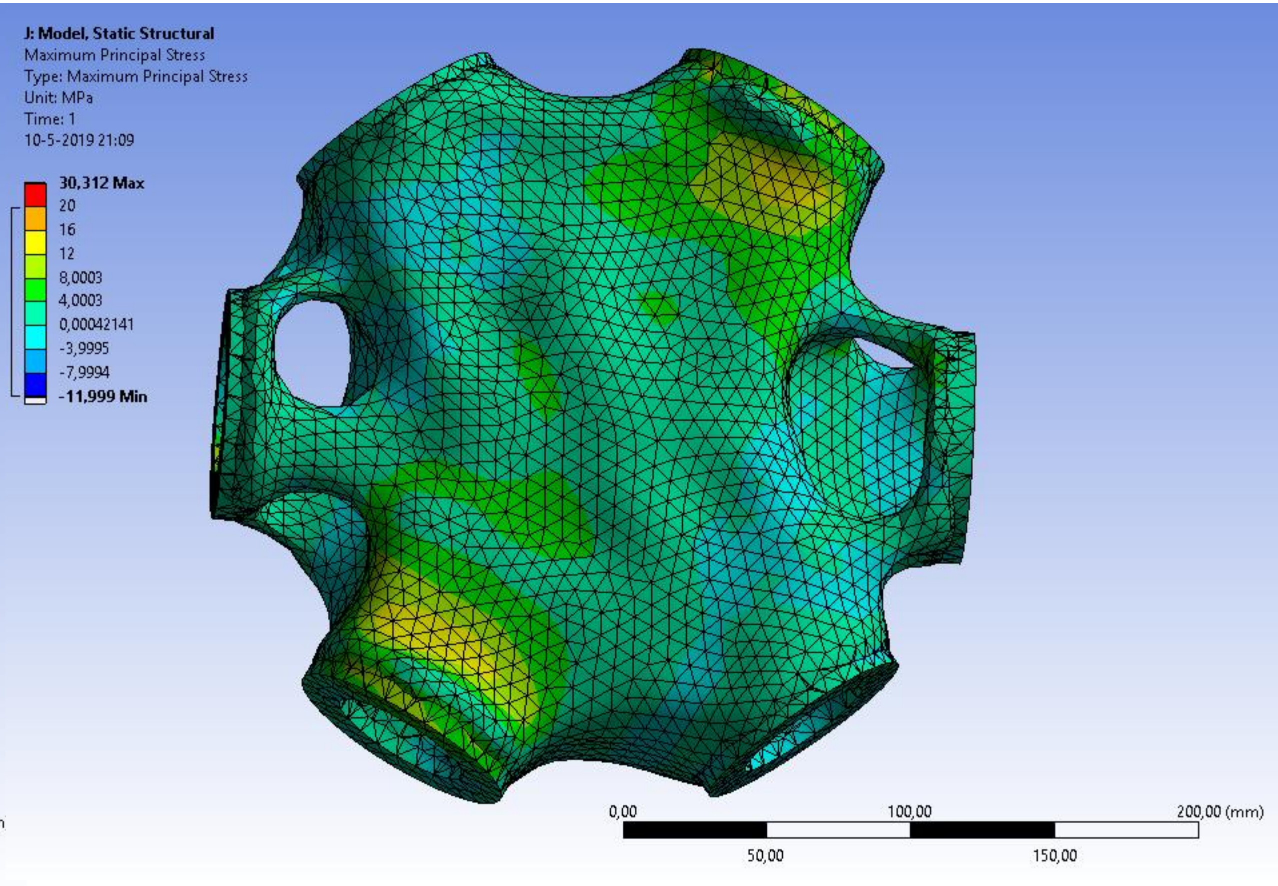


shell load

added load



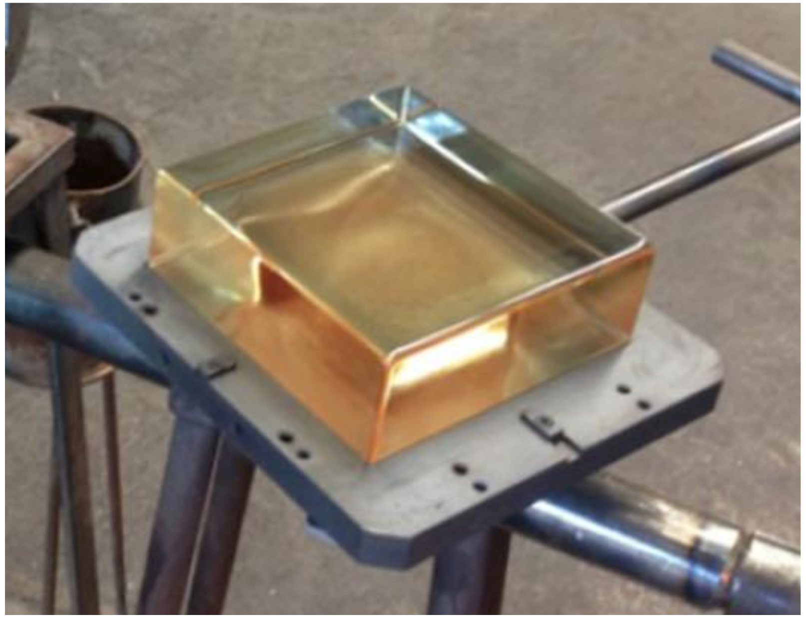

J: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
10-5-2019 21:09
30,312 Max
20
16
12
8,0003
4,0003
0,00042141
-3,9995
-7,9994
-11,999 Min
0,00
100,00
200,00 (mm
50,00
150,00

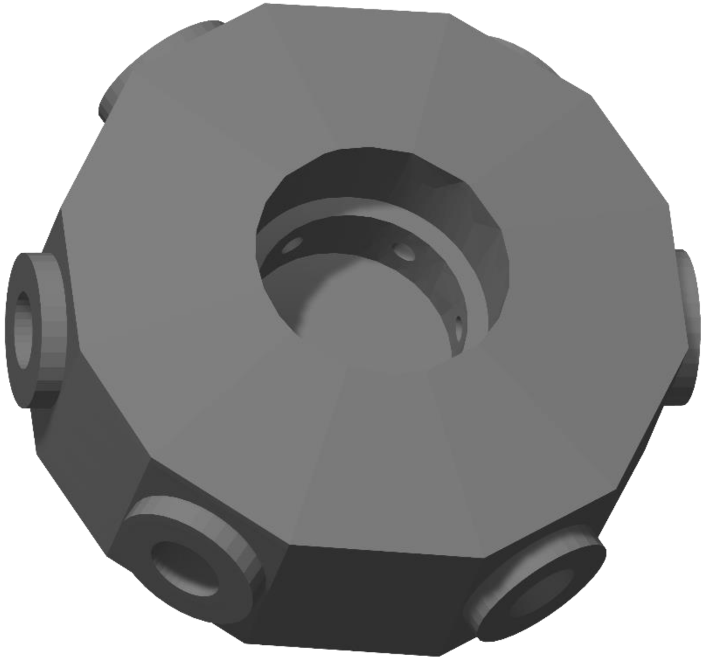

J: Model, Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
10-5-2019 21:09
30,312 Max
20
16
12
8,0003
4,0003
0,00042141
-3,9995
-7,9994
-11,999 Min
0,00
100,00
200,00 (mm)
50,00
150,00

wind load

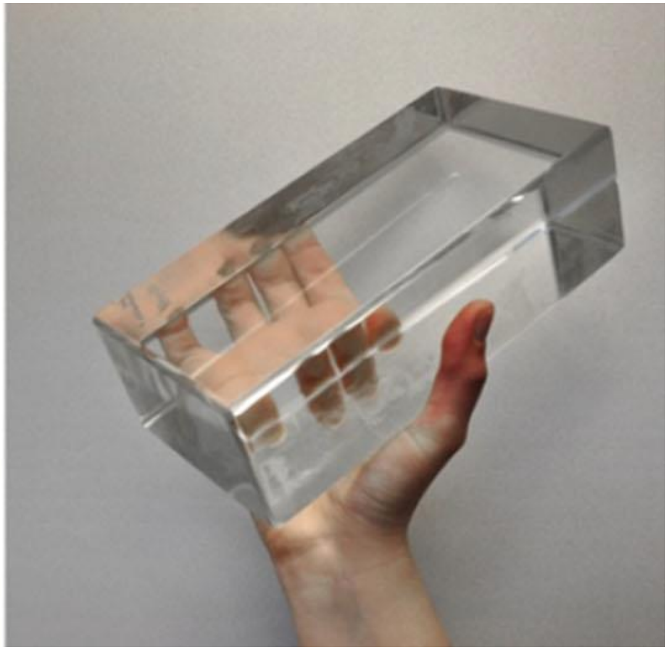
Annealing times

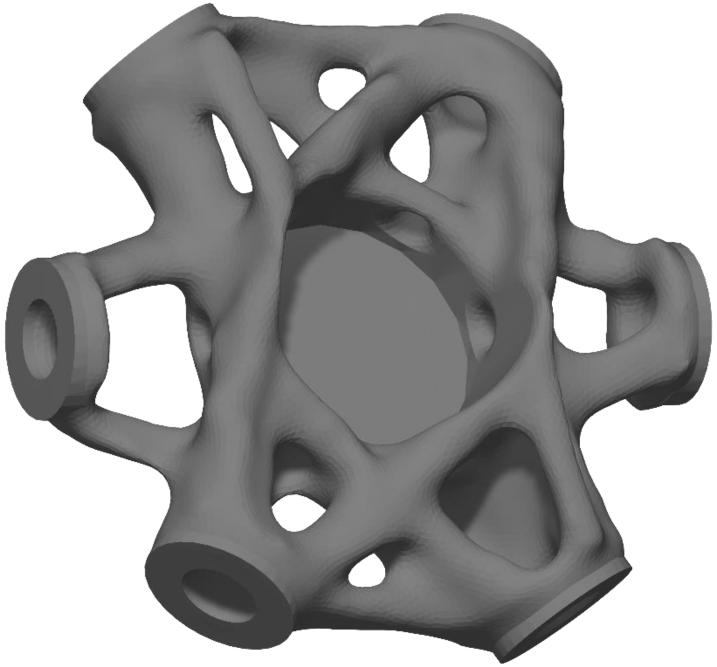

MVRDV
CHANEL
Agent Provocateur
ANNE FONTAINE



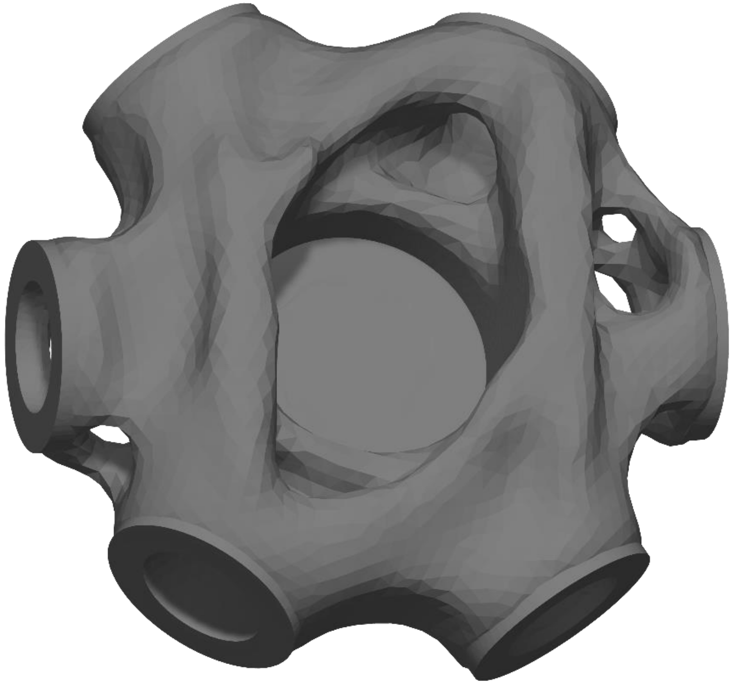


Object	Crystal House brick		Un-optimised node
Size	210 x 210 x 65 mm		240 x 240 x 95 mm
Mass	7.2 kg		9 kg
Annealing	38 h	>	**approx. 48+ h**



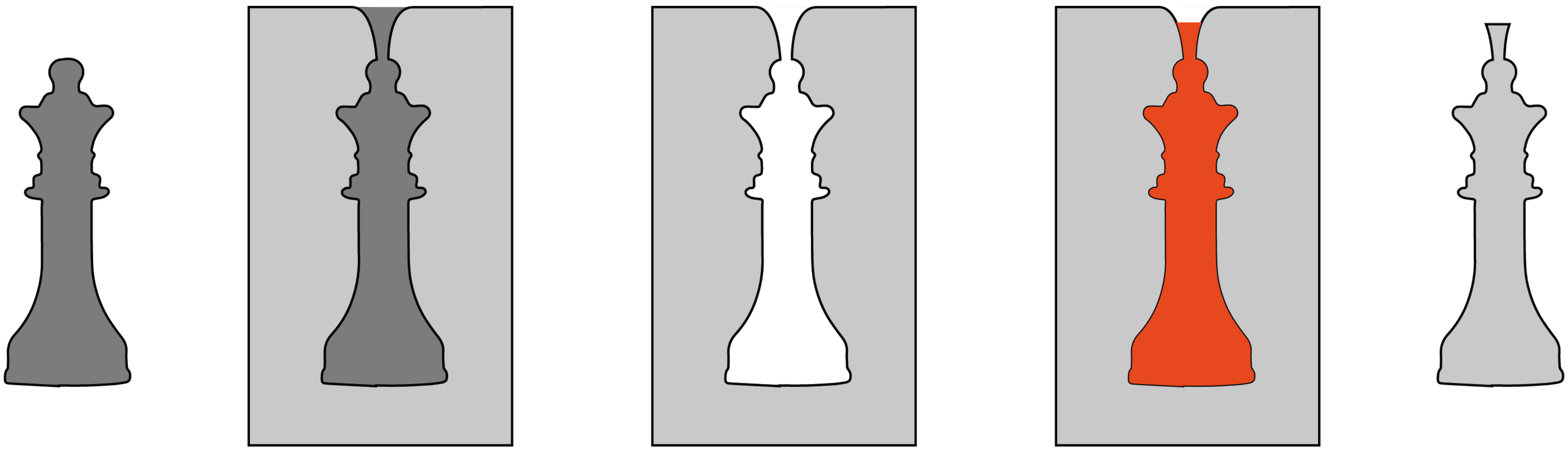


Object	Crystal House brick		Two-load optimised node
Size	210 x 105 x 65 mm		Max 30 mm section
Mass	3.6 kg		2.7 kg
Annealing	8 h	>	**approx. 4 h**



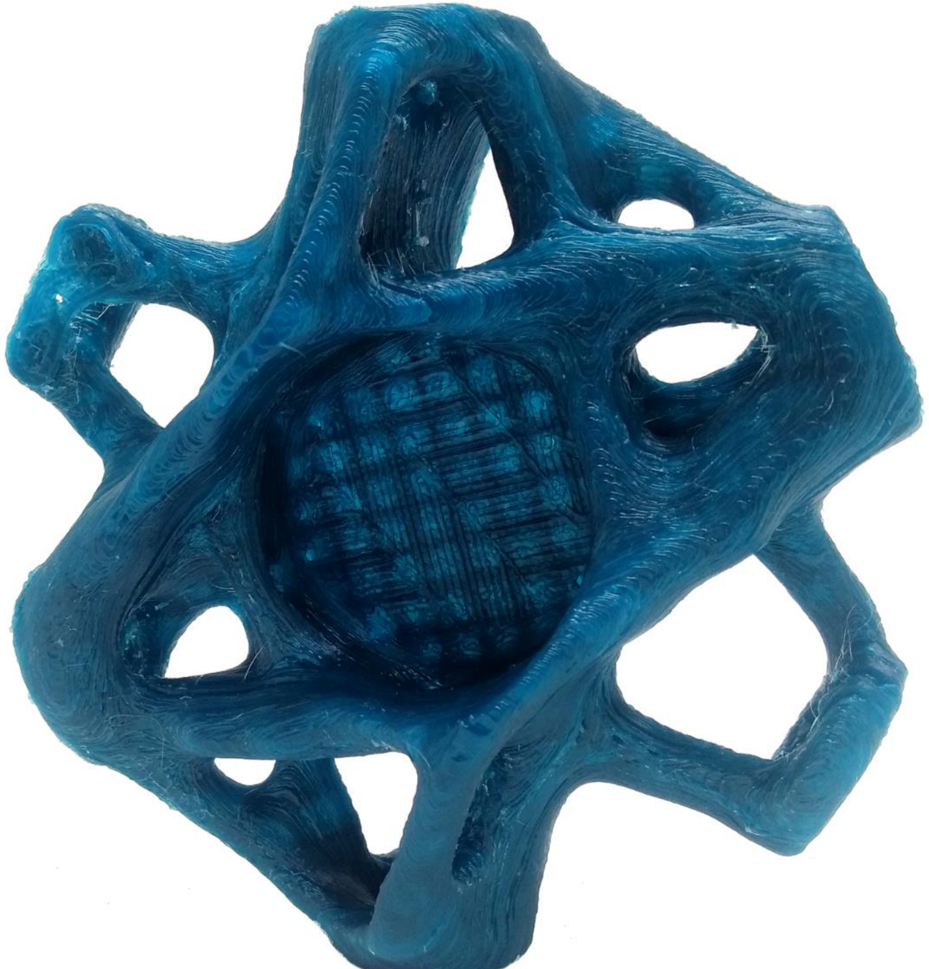
Object	Crystal House brick		Heavy optimised node
Size	210 x 167.5 x 65 mm		Max 40 mm section
Mass	5.4 kg		5.1 kg
Annealing	20 h	>	**approx. 16 h**

prototyping



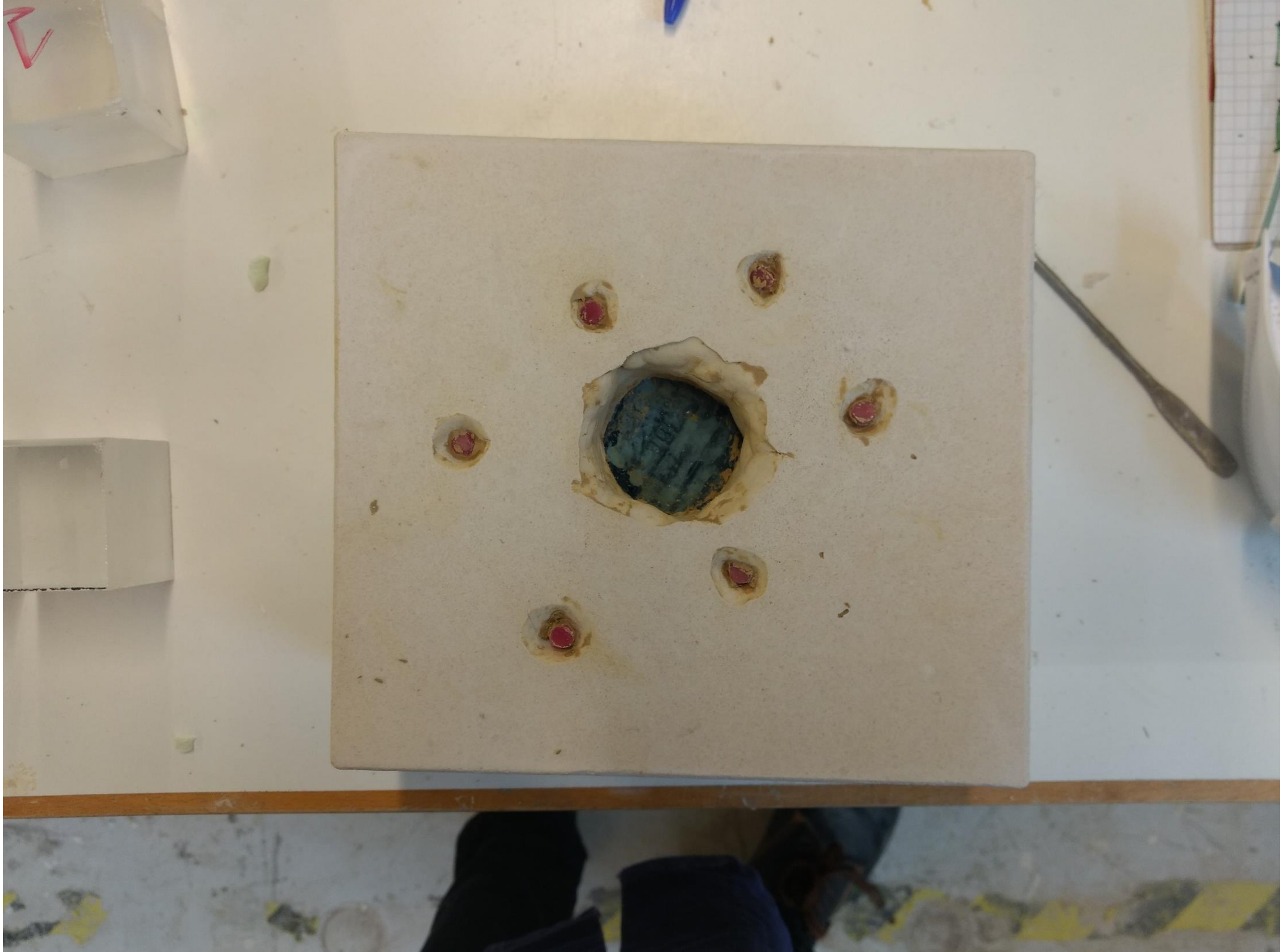
lost-wax casting

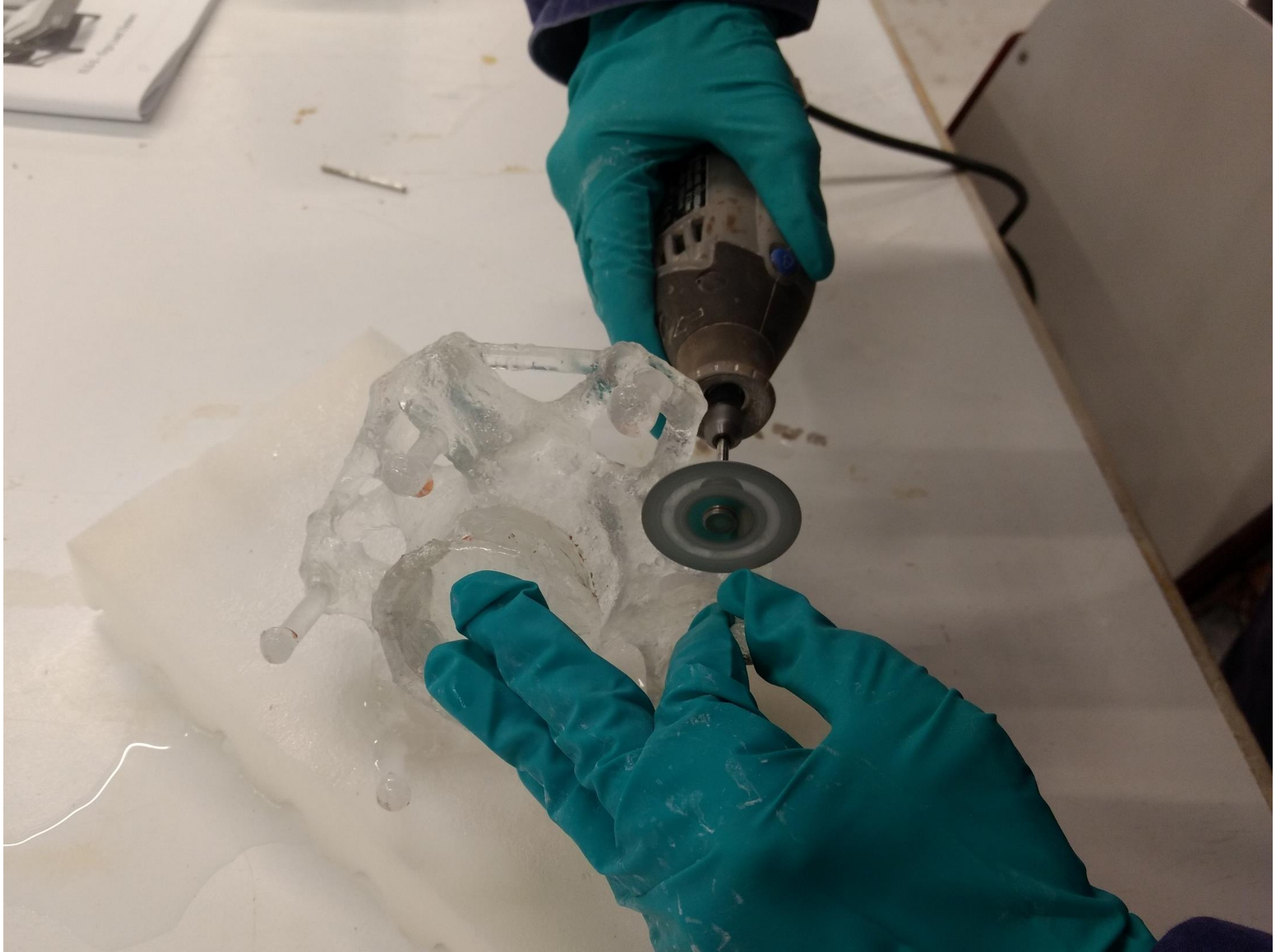
sand mould casting

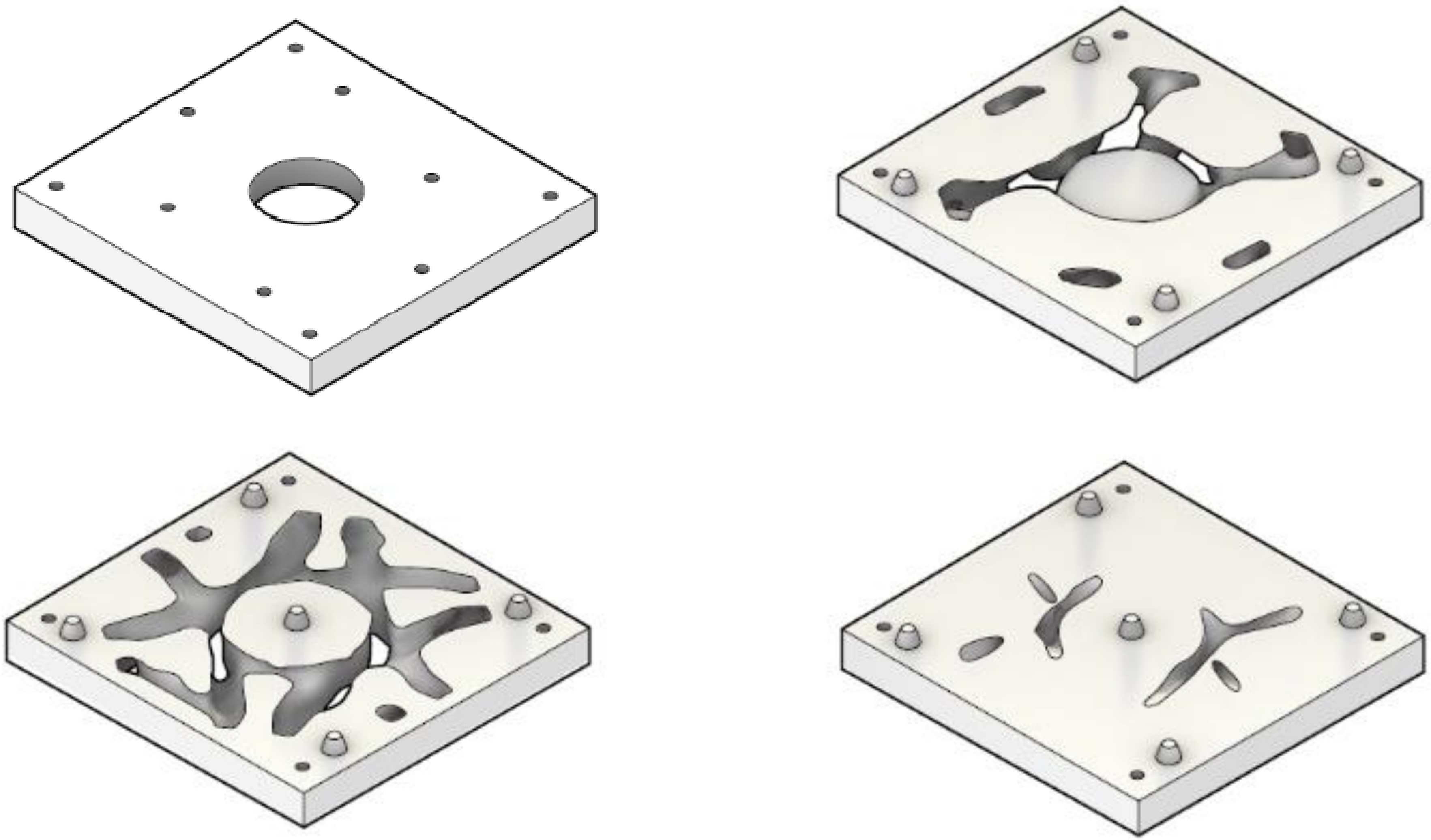


printed wax node

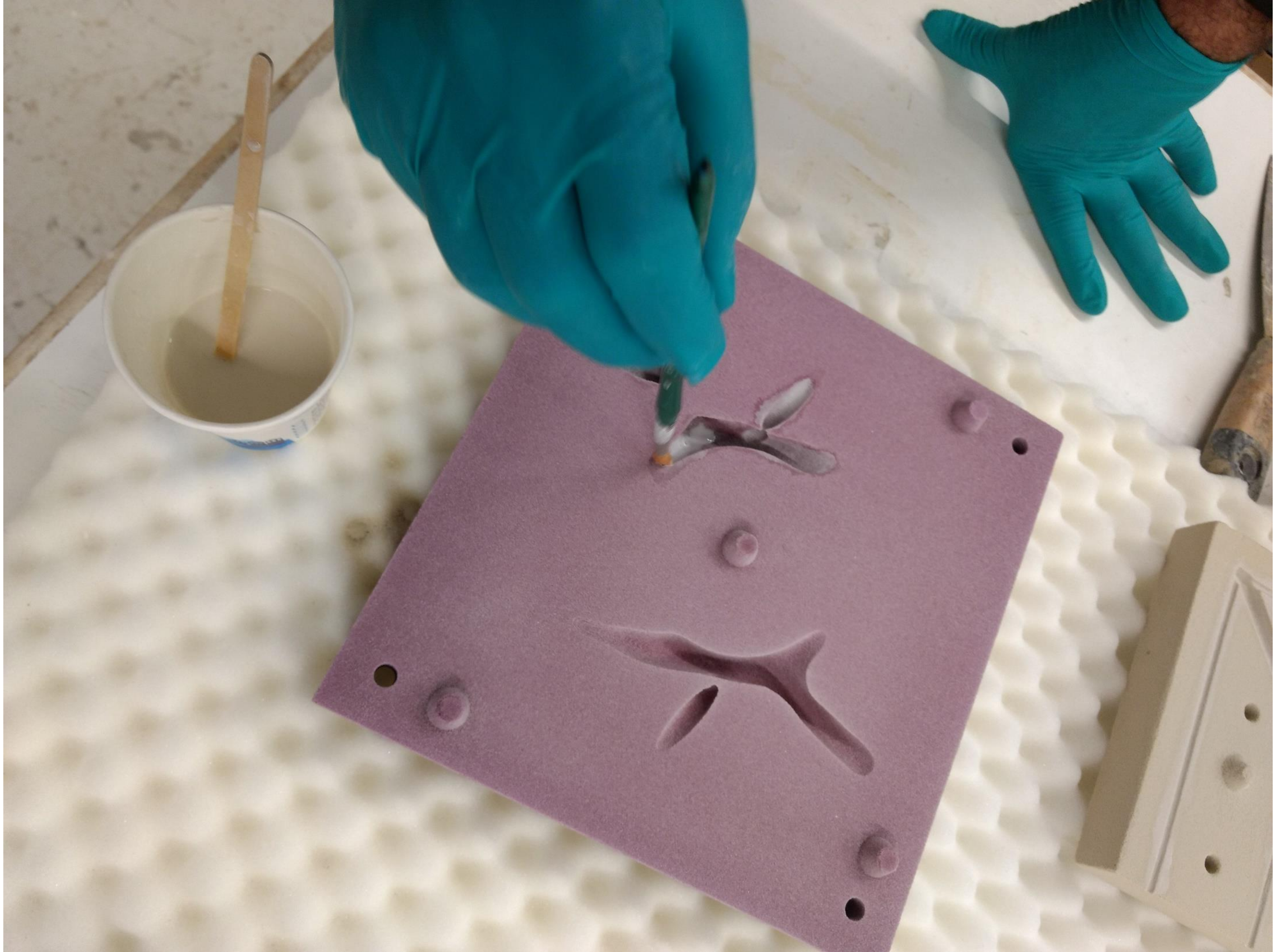

IRWIN
QUICK-GRIP
Quick
CHANGE



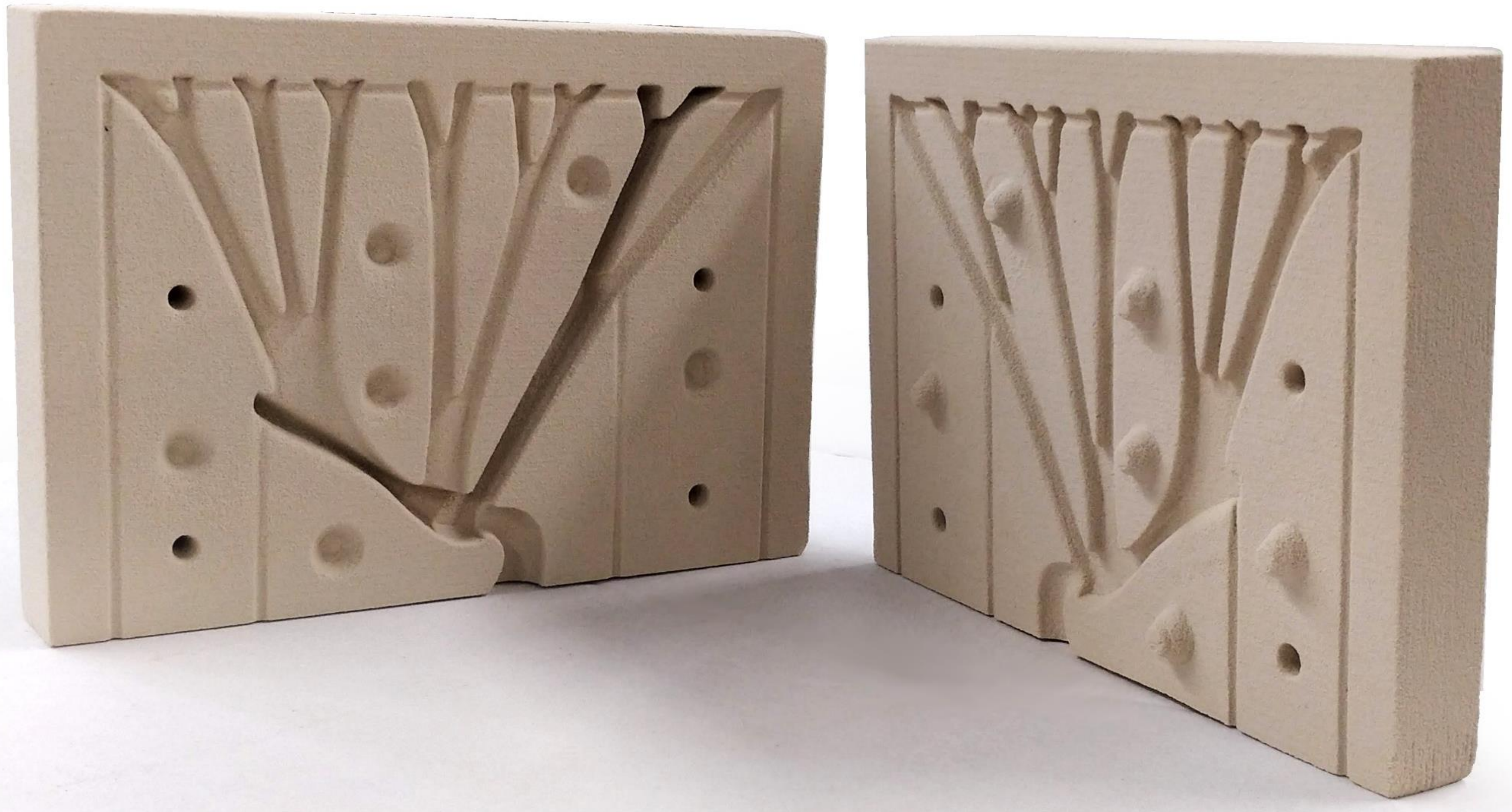




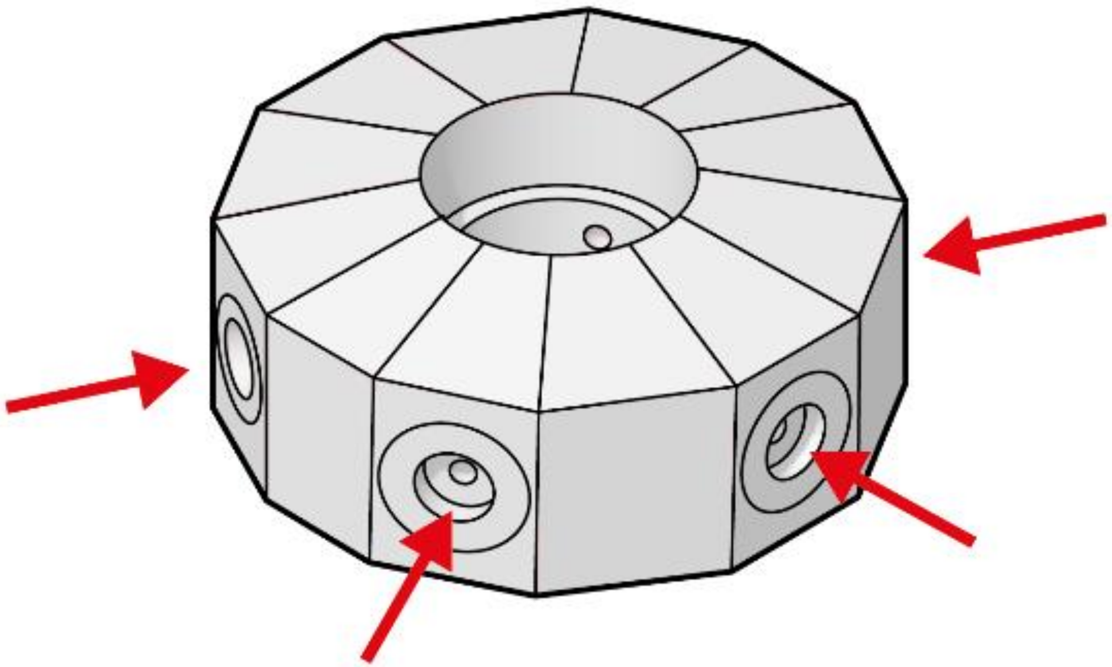
sand mould casting

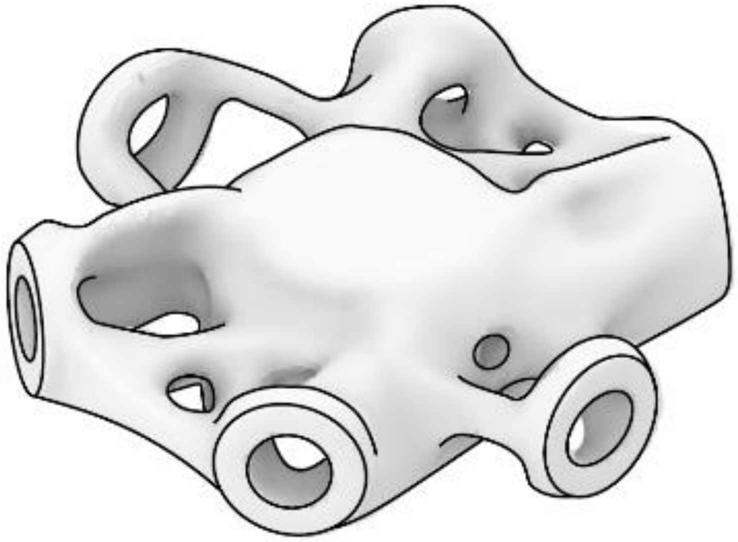



WILFRIED

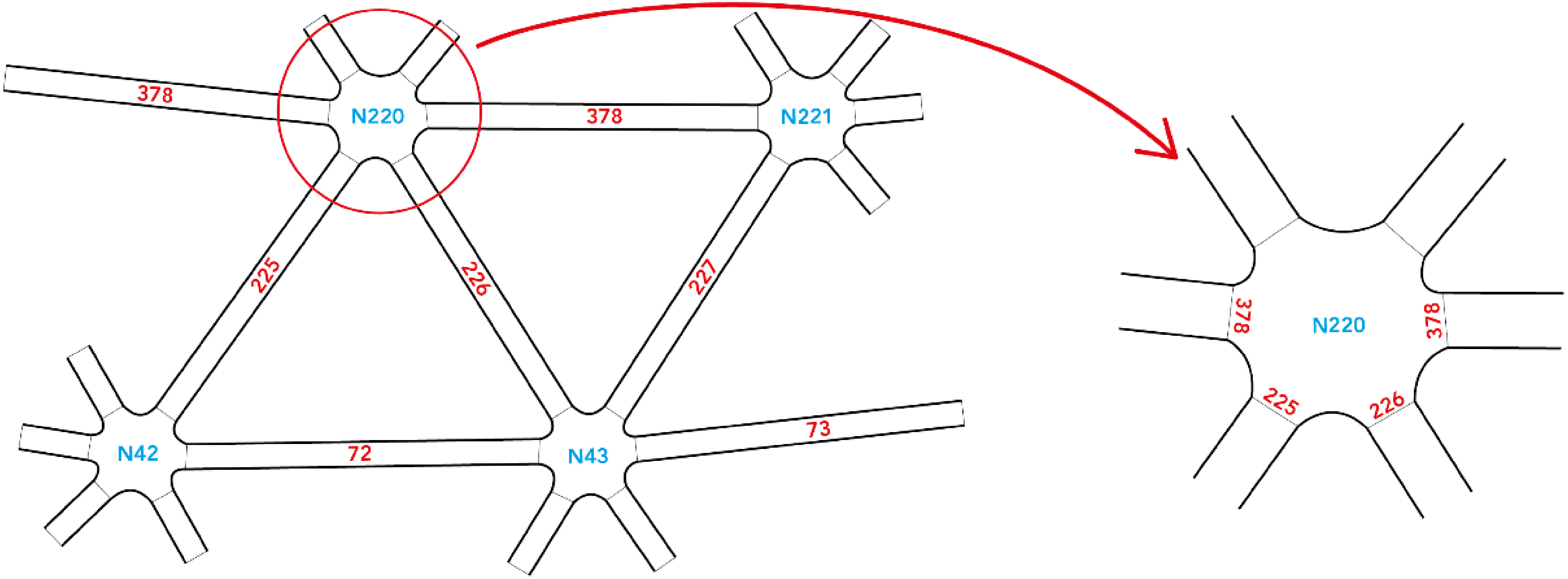


fabrication and assembly

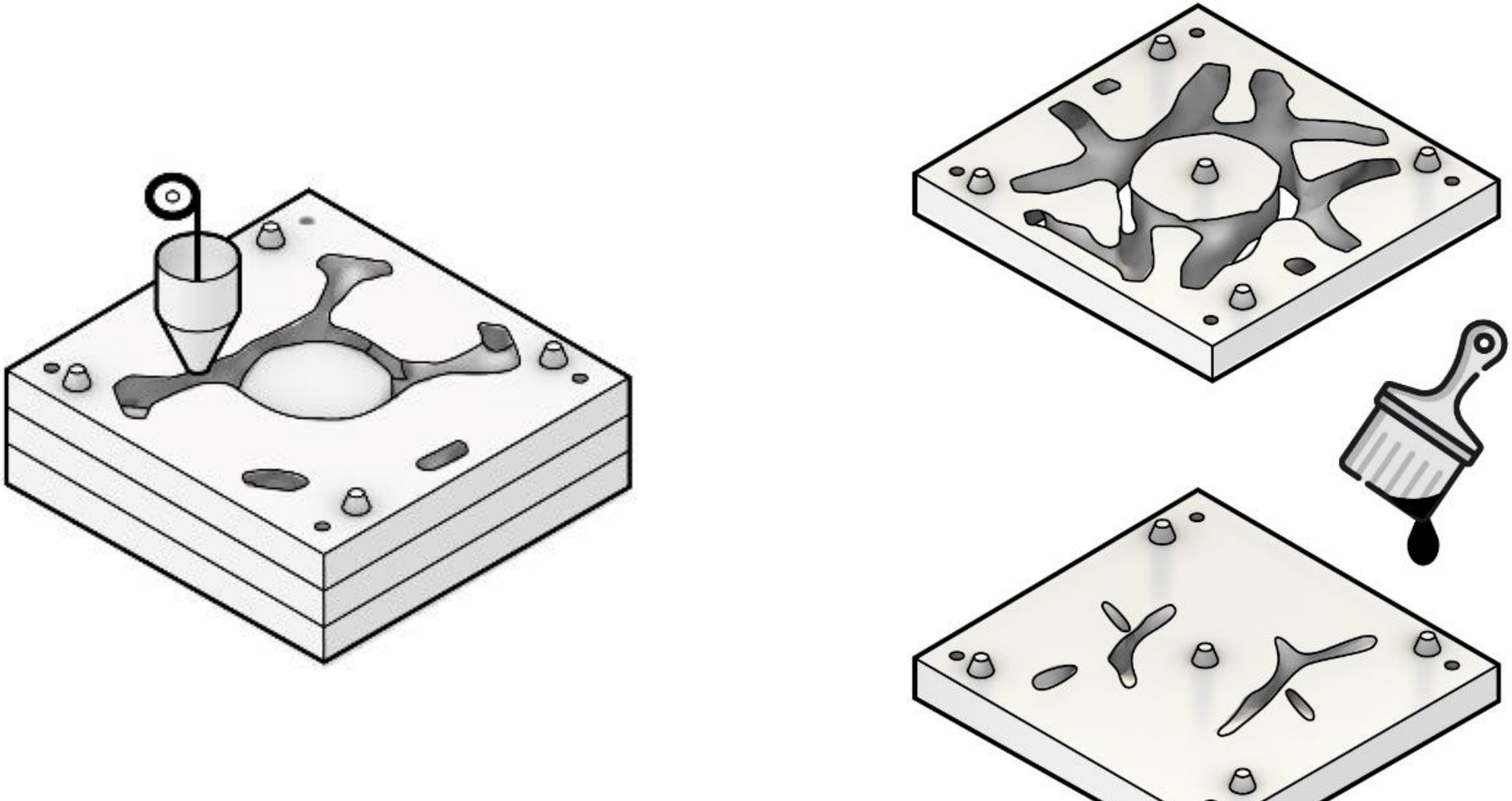




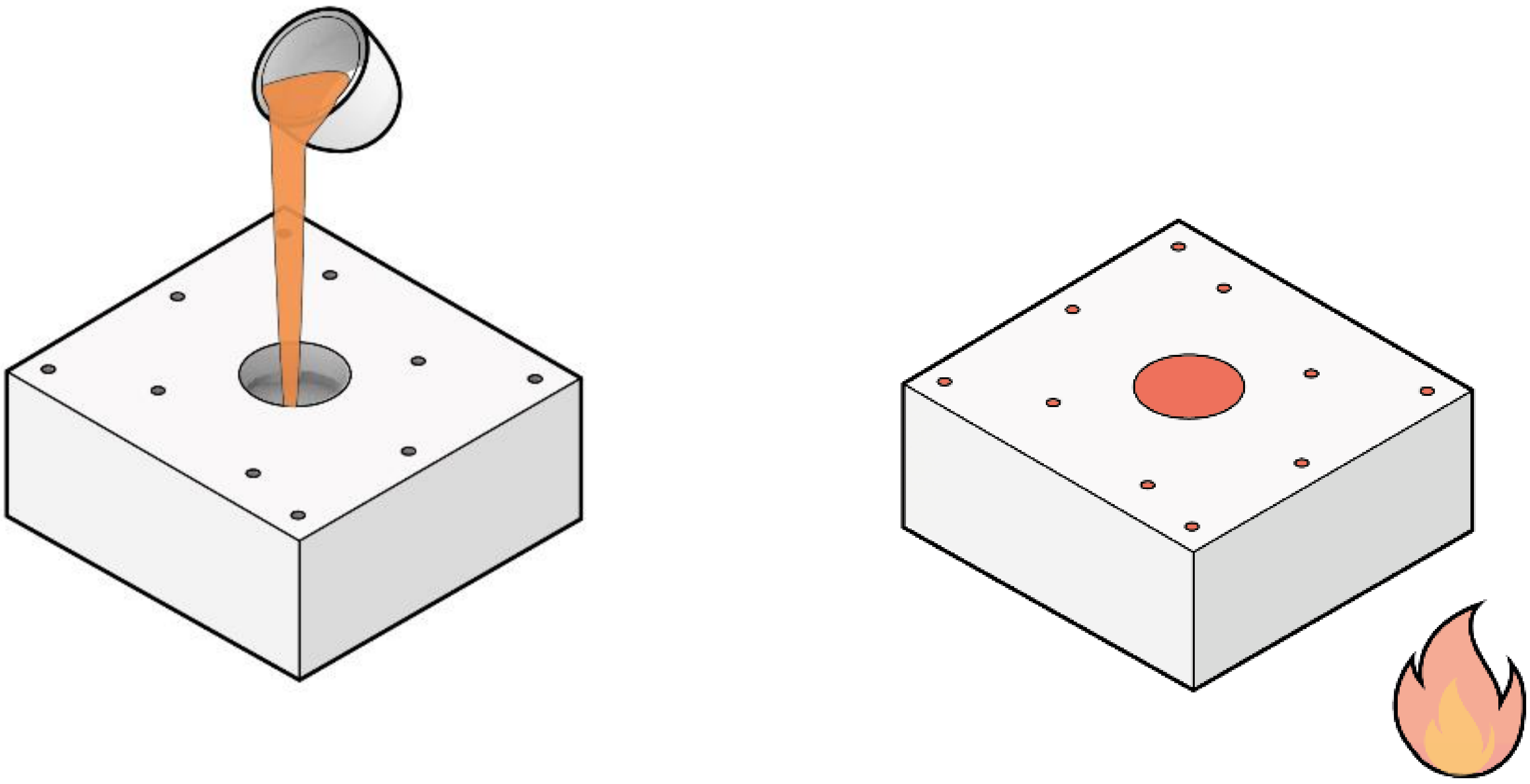
optimisation



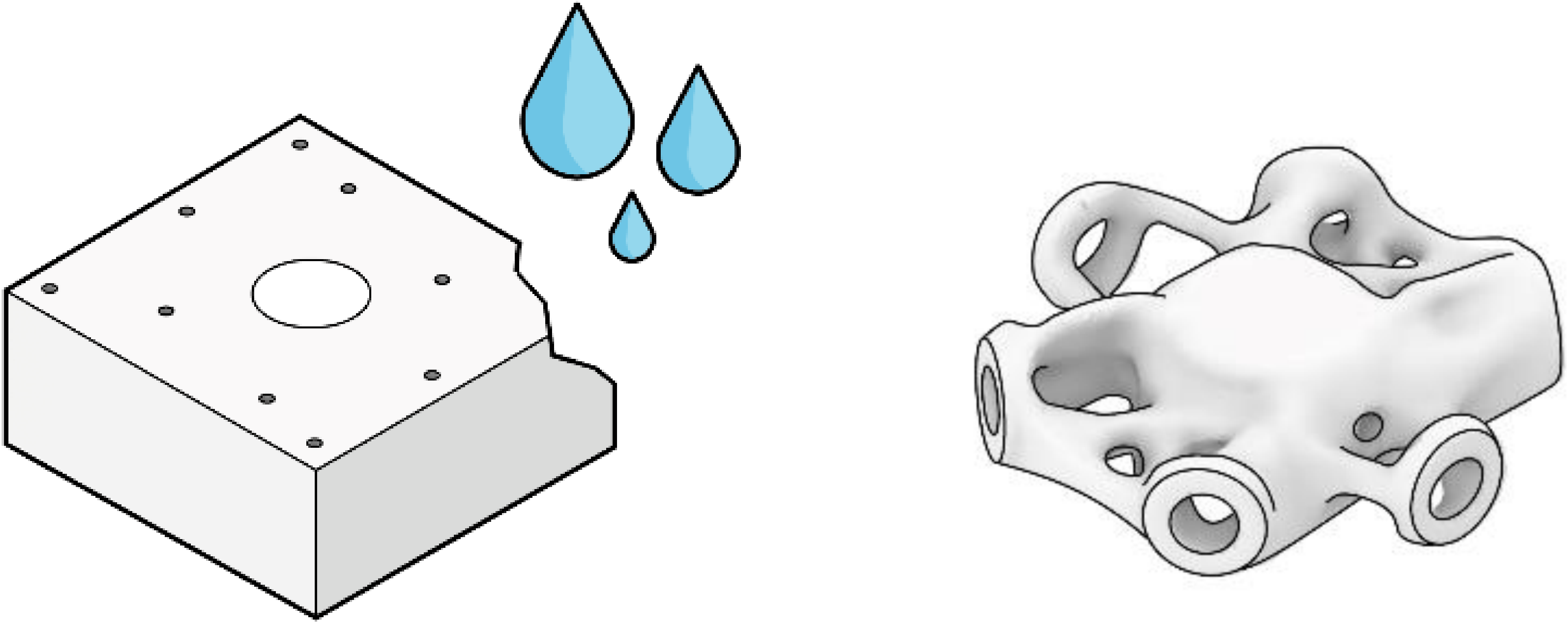
labeling



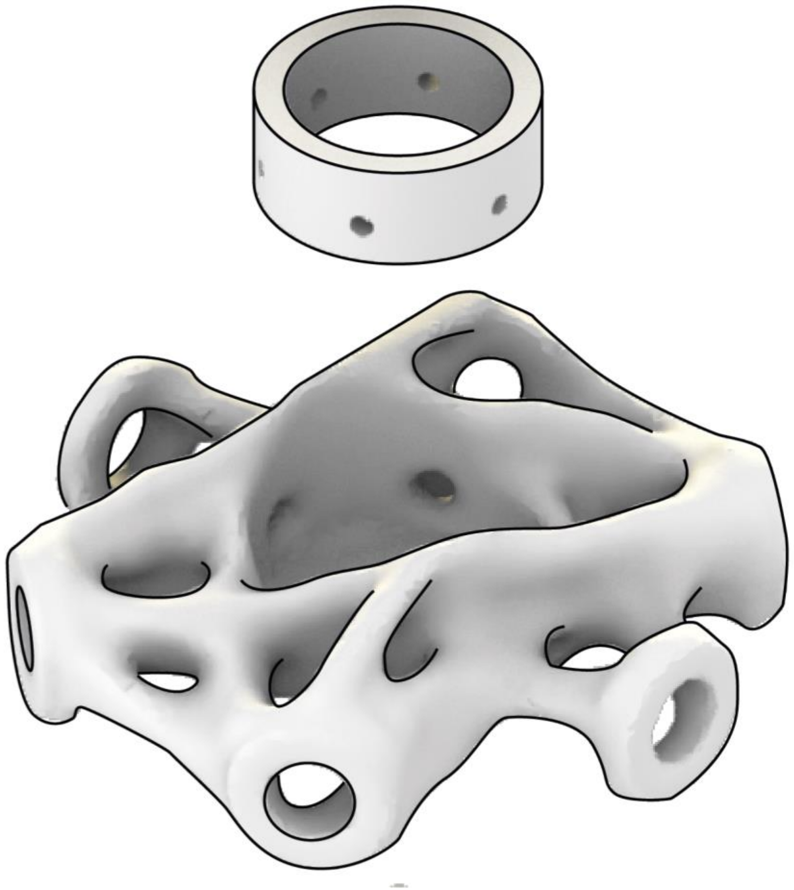
sand mould printing and coating



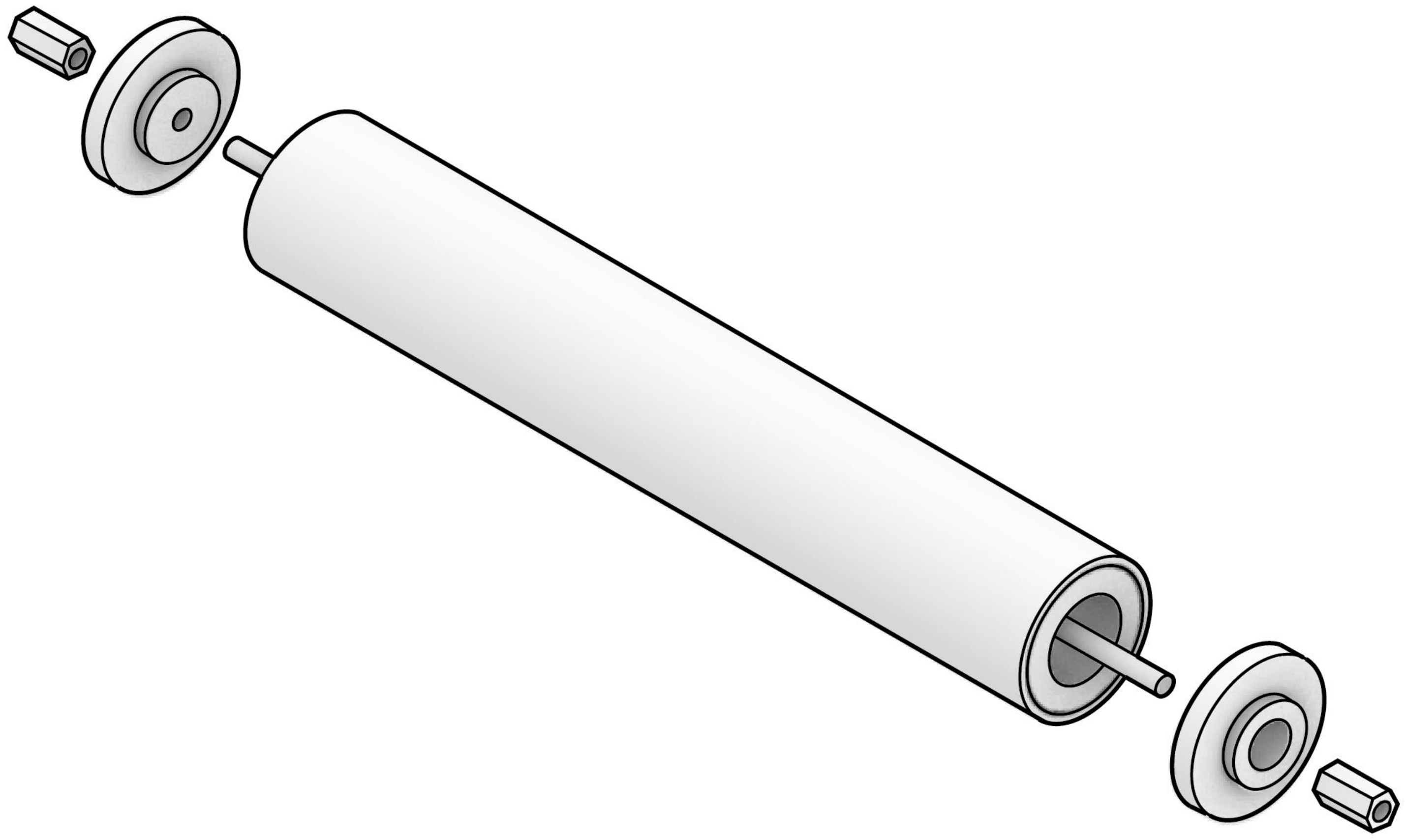
casting and annealing



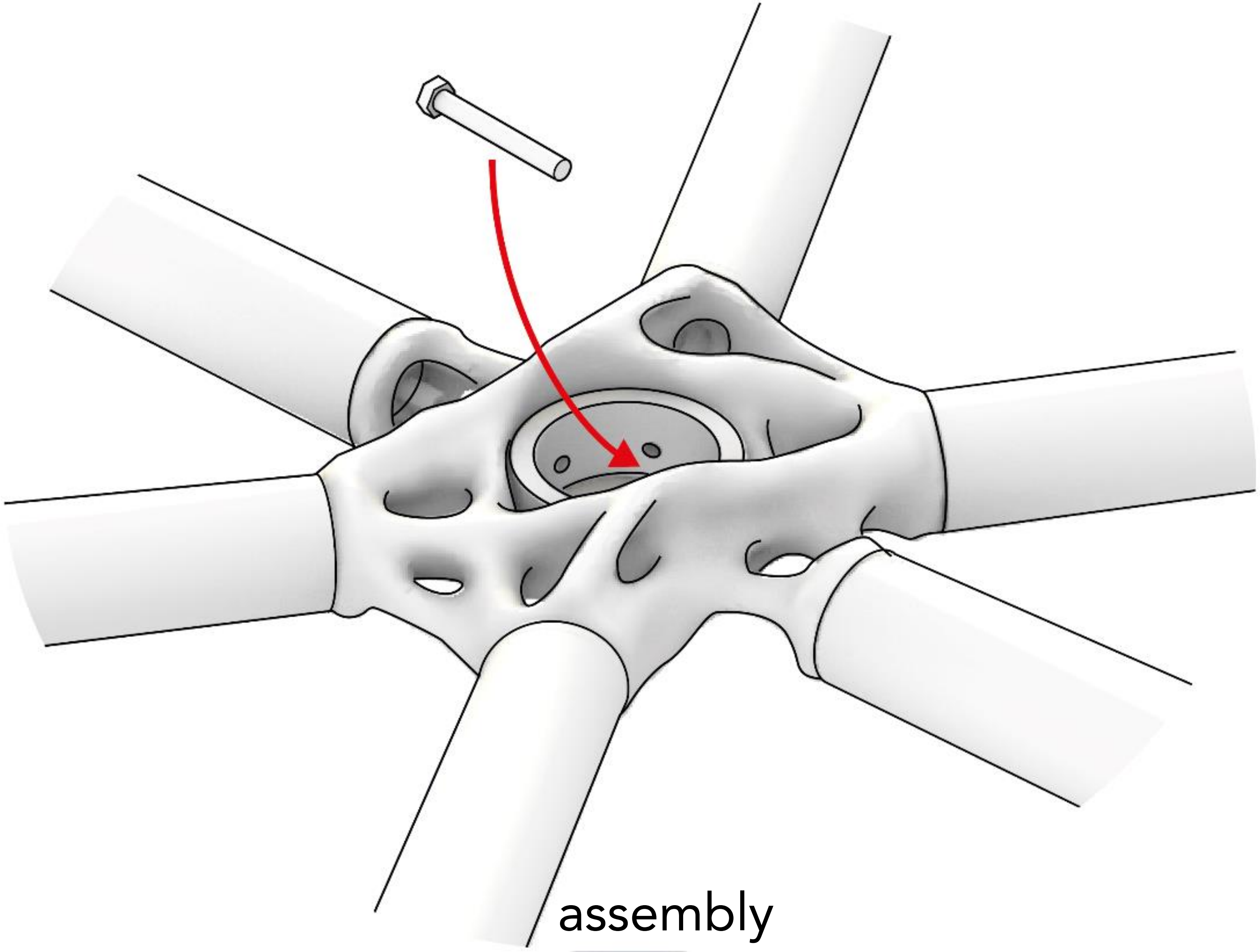
demoulding



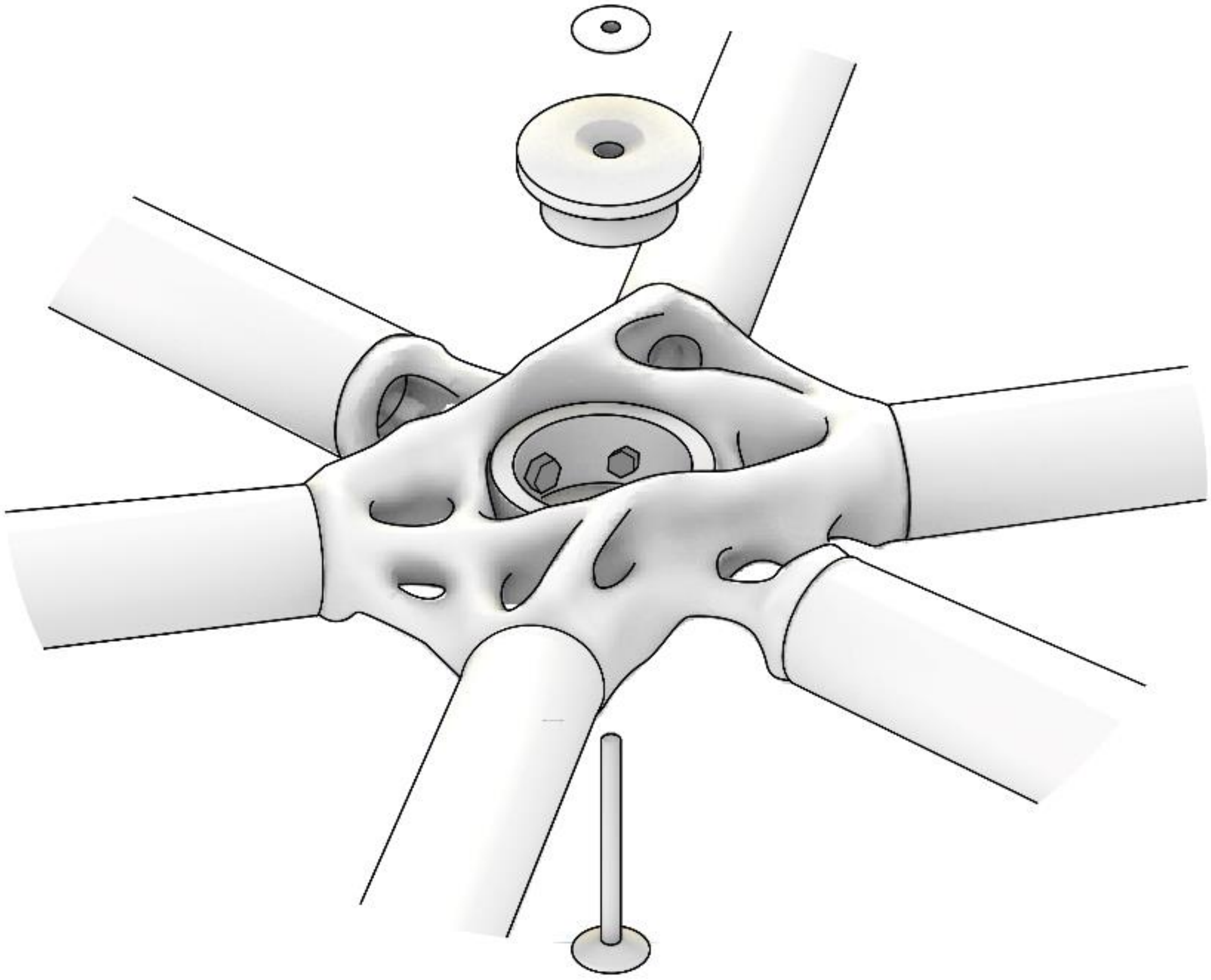
assembly

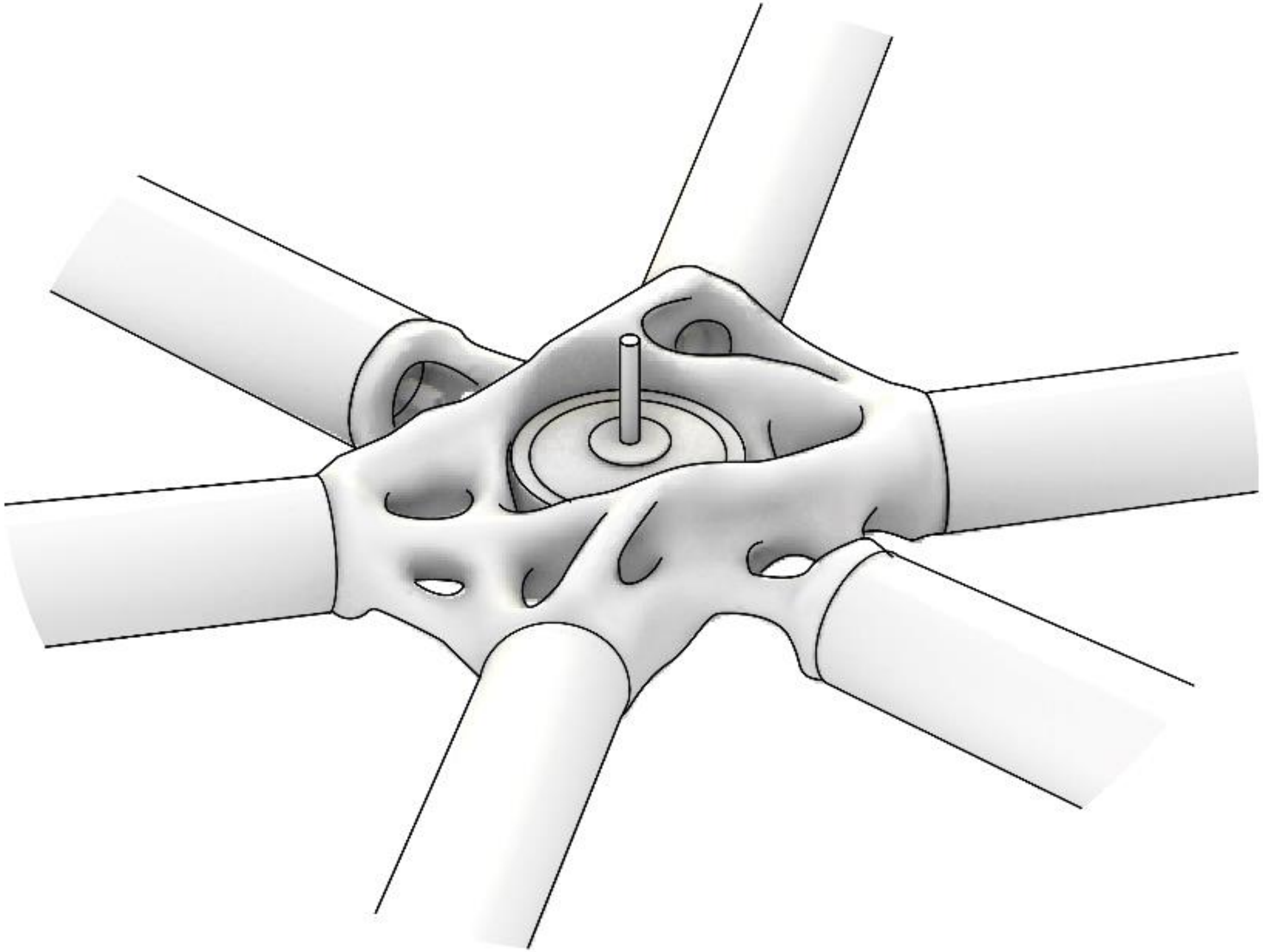


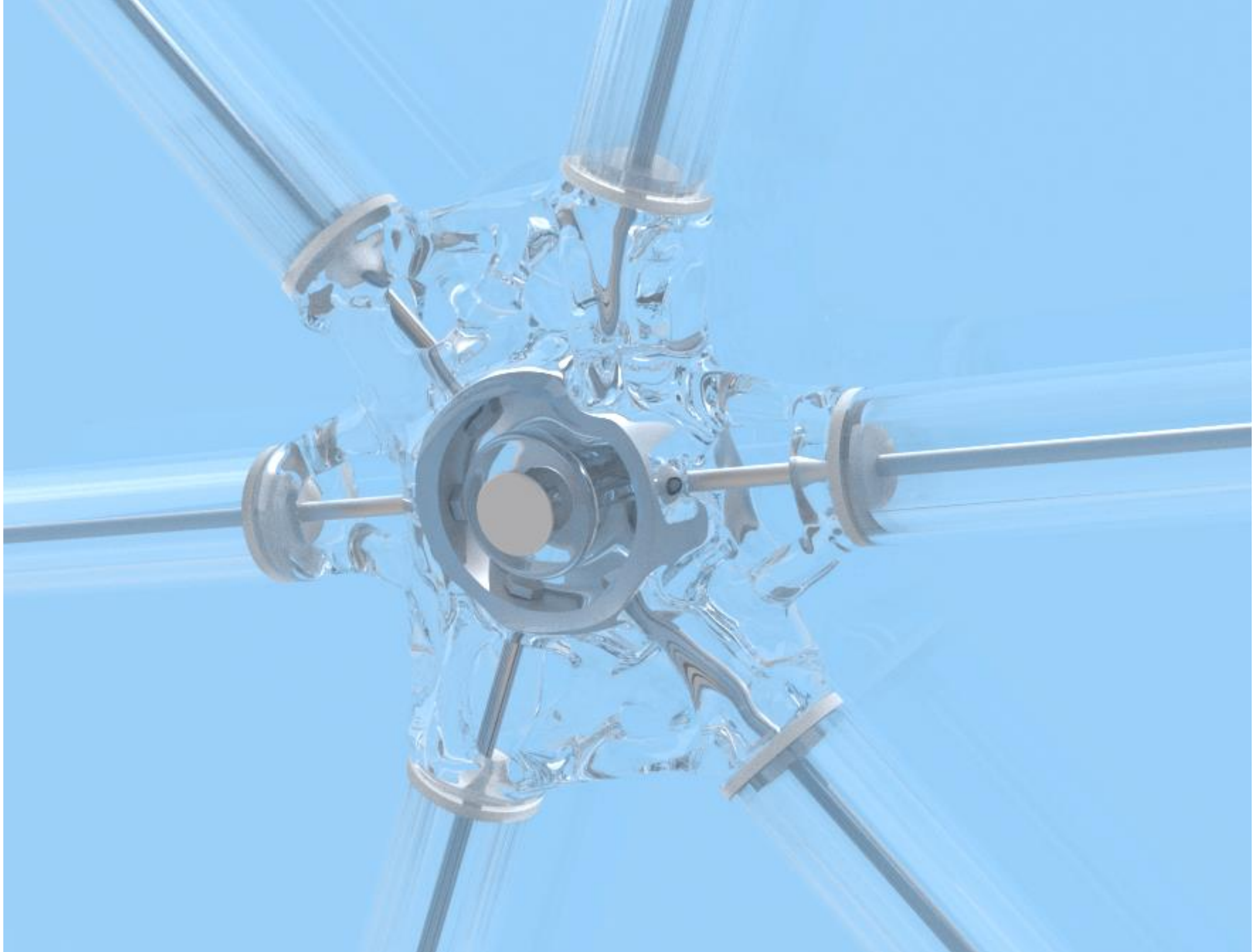
assembly

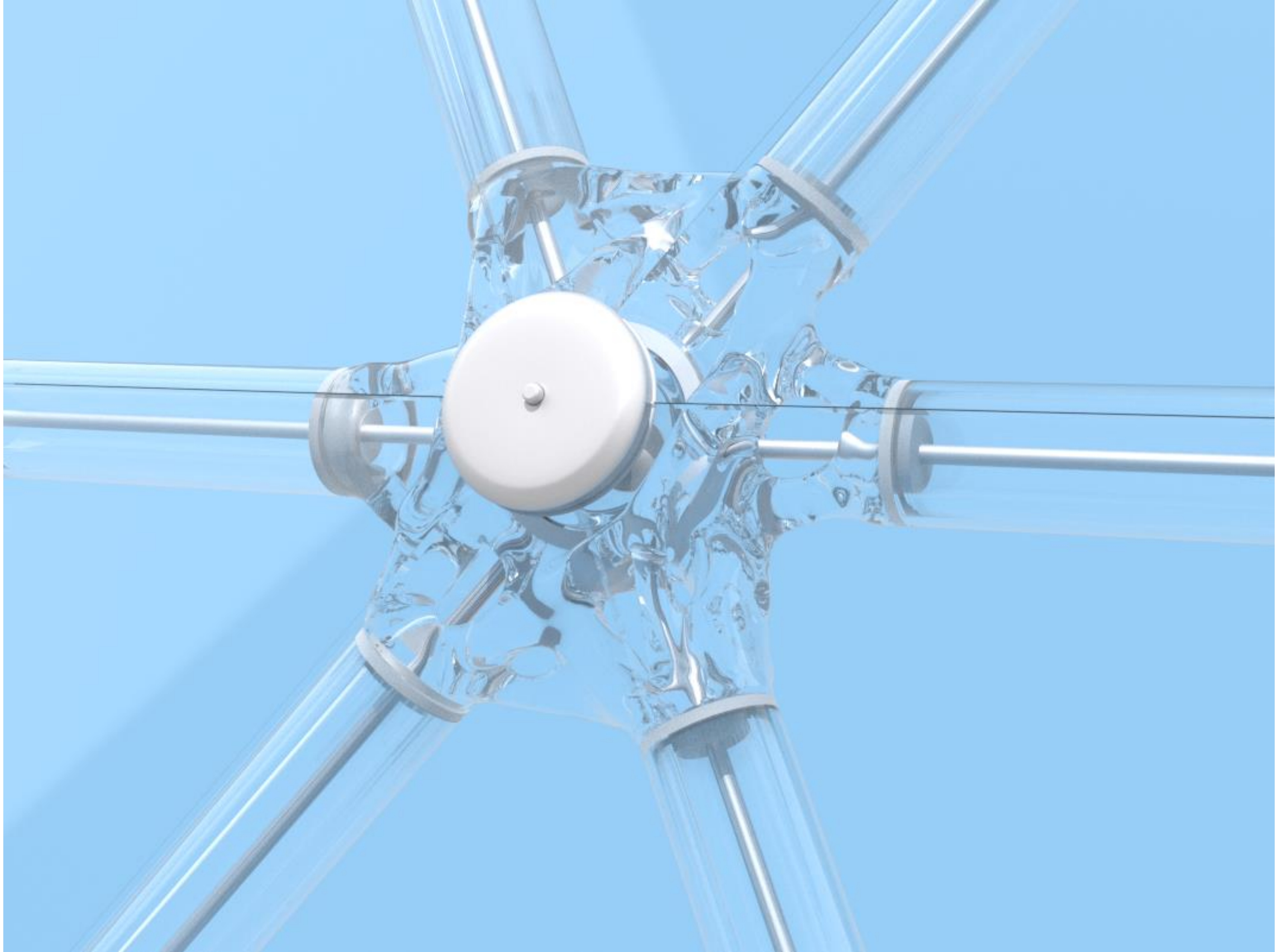


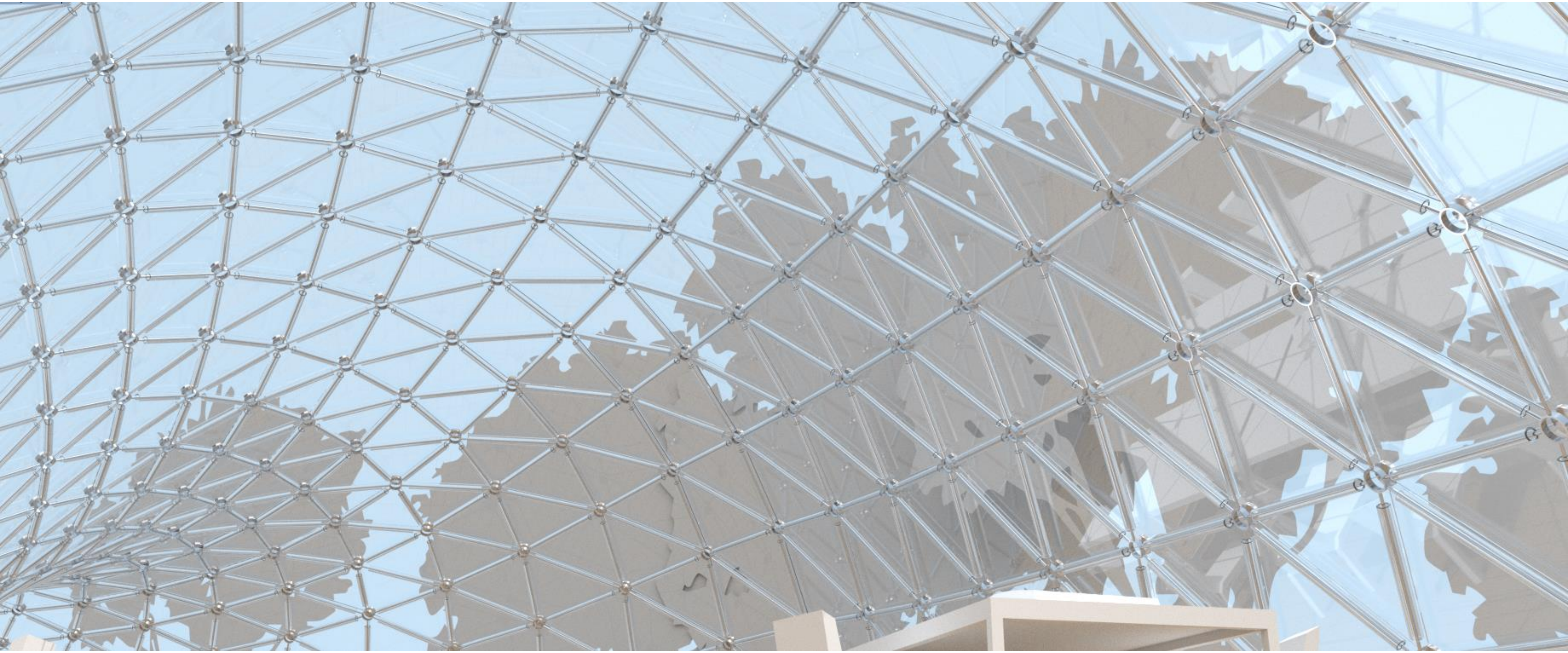
assembly











Conclusion

What is the potential of using Topology Optimisation as a design tool for a structural cast glass grid shell node that is optimised for fabrication, structural behaviour and assembly?

Conclusion

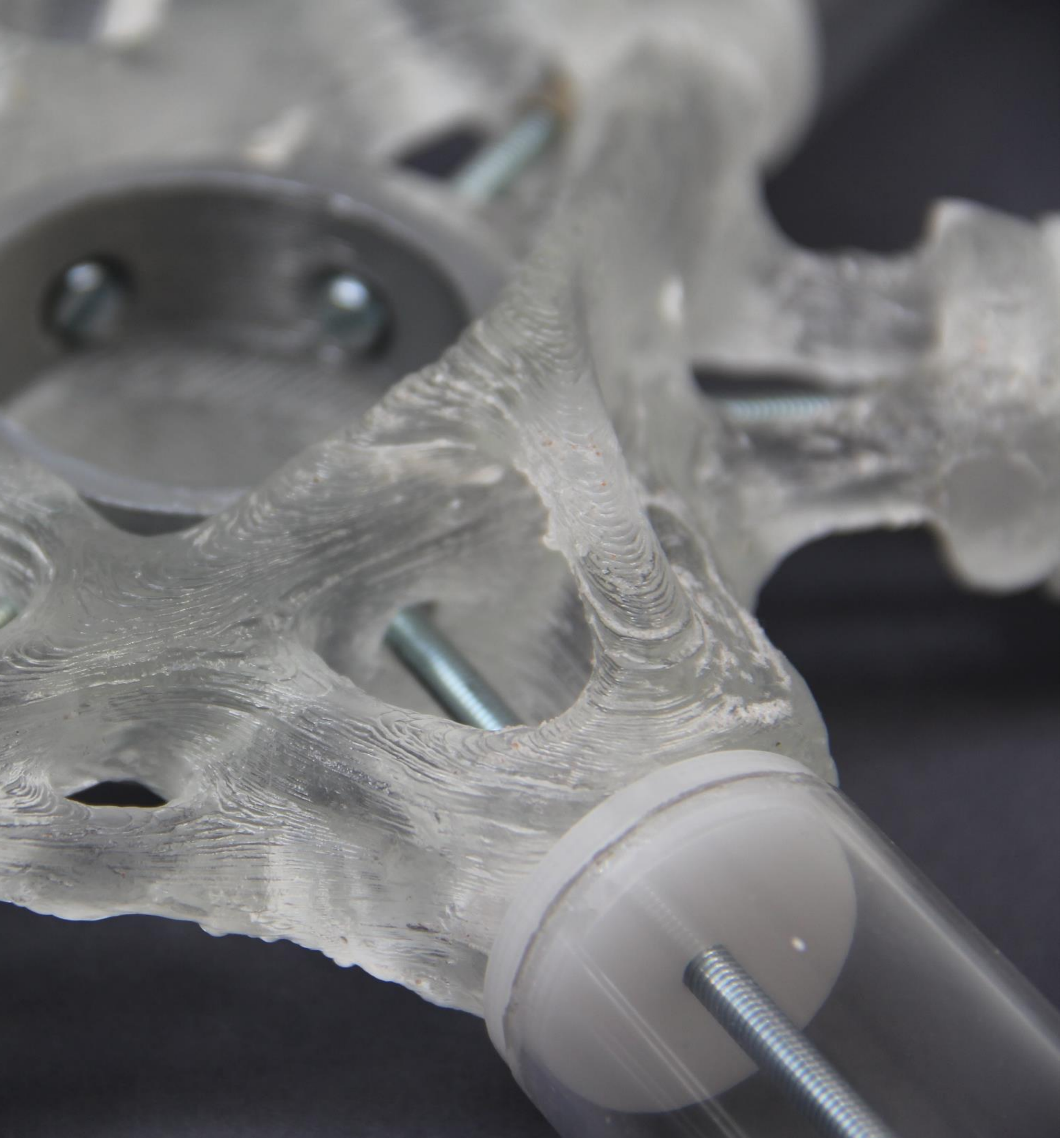
Topology Optimisation has the potential to greatly improve cast glass as a structural material by improving material efficiency and significantly reducing annealing times.

Conclusion

Additive manufacturing makes it possible to fabricate these geometries, and offers the possibility to concentrate the complexity of the design in a single component

Lesson learned

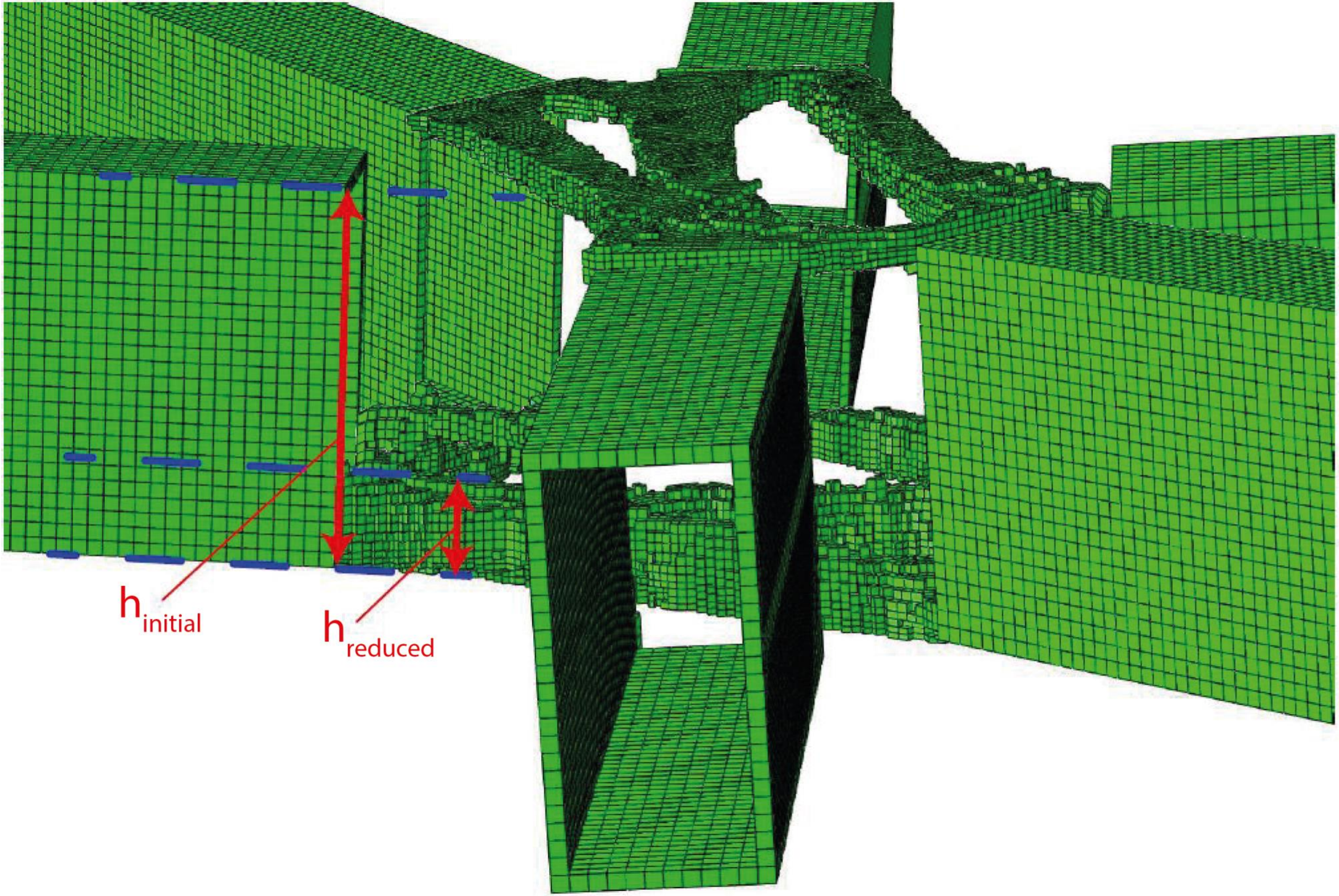
Topology Optimisation can be a powerful tool, but has very specific applications



acknowledgements

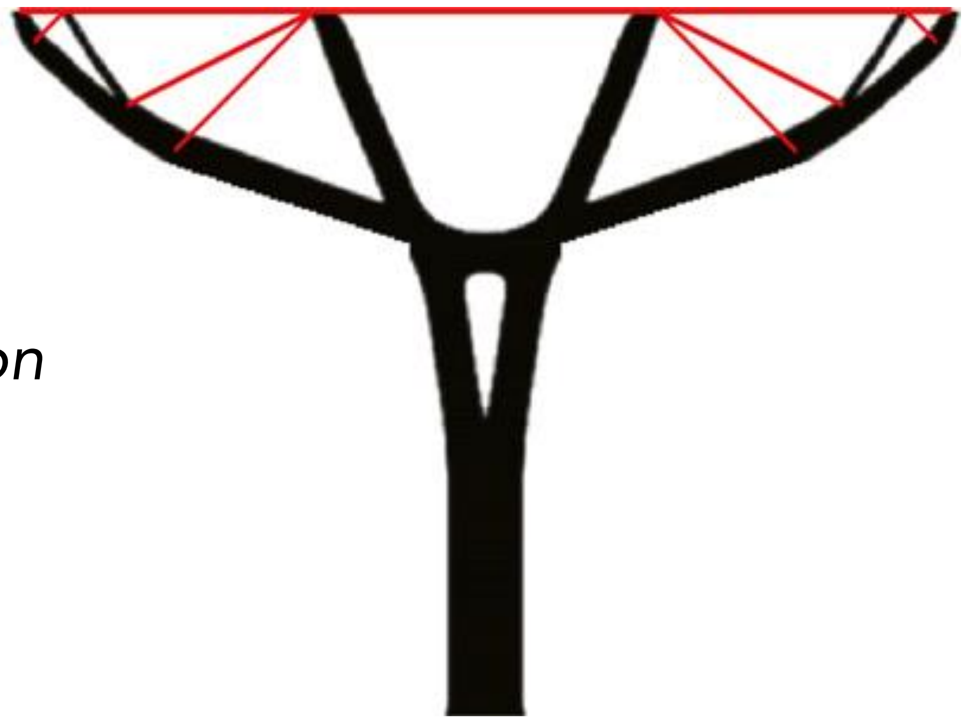
Illustrations

p. 5: Peter Aaron, from https://architizer.com/projects/apple-store-fifth-avenue/
p. 6: Enclos, from http://www.enclos.com/service-and-technology/technology/structural-glass-facades/facade-structures/glass-fin
p. 7: MVRDV, from https://www.mvrdv.nl/projects/240/crystal-houses
Koji Fuji / Nacasa & Partners Inc, from https://www.archdaily.com/885674/optical-glass-house-hiroshi-nakamura-and-nap
p. 8: Australbricks, from https://australbricks.com.au/nsw/product/venetian-glass
p. 9-12: Corning Museum of glass, from https://www.youtube.com/watch?v=qBIsNNPRseQ
p. 15: SCHOTT/ESO, from https://www.eso.org/public/images/eso1715a/
p. 16: Giant Magellan Telescope https://www.gmto.org/gallery/mirror-lab/
p. 20: Weaver, T. (September 2016) Inside Track; 3D printing the Light Rider. Develop 3D, 20-24.
p. 21: Prayudhi, B. (2016) 3F3D: Form Follows Force with 3D printing; Topology Optimisation for Free-form Building Envelope design with Additive Manufacturing. Master Thesis, Faculty of Architecture and the Built Environment, TU Delft. Retrieved from: https://repository.tudelft.nl/islandora/object/uuid%3Ab068f81c-1561-4733-a07d- 05e60368184b in November 2018.
p. 23: Schlaich Bergermann Partner, https://www.sbp.de/en/project/museum-for-hamburg-history-courtyard-roof/
p. 26: P. Aldrupp., 2014. Recieved in personal correspondence with A. Sevtsuk.
p. 28: Carpeter Lowings, https://carpenterlowings.com/portfolio_page/glass-tube-field/,
p. 30: Ate Snijder, from private correspondence
p. 51: Cimri, from https://www.cimri.com/2-kisilik-kamp-cadiri?sort=price,asc&page=1
p. 65: MVRDV, from https://www.mvrdv.nl/projects/240/crystal-houses
p. 71: Galjaard, S., Hofman, S., Perry, N., Ren, S. (2015) Optimizing Structural Building Elements in Metal by uaing Additive Manufacturing. Proceedings of the International Association for Shell and Spacial Structures Symposium, August 2015, Amsterdam, The Netherlands.
p. 83/88: Ivneet Bhatia, from personal correspondence



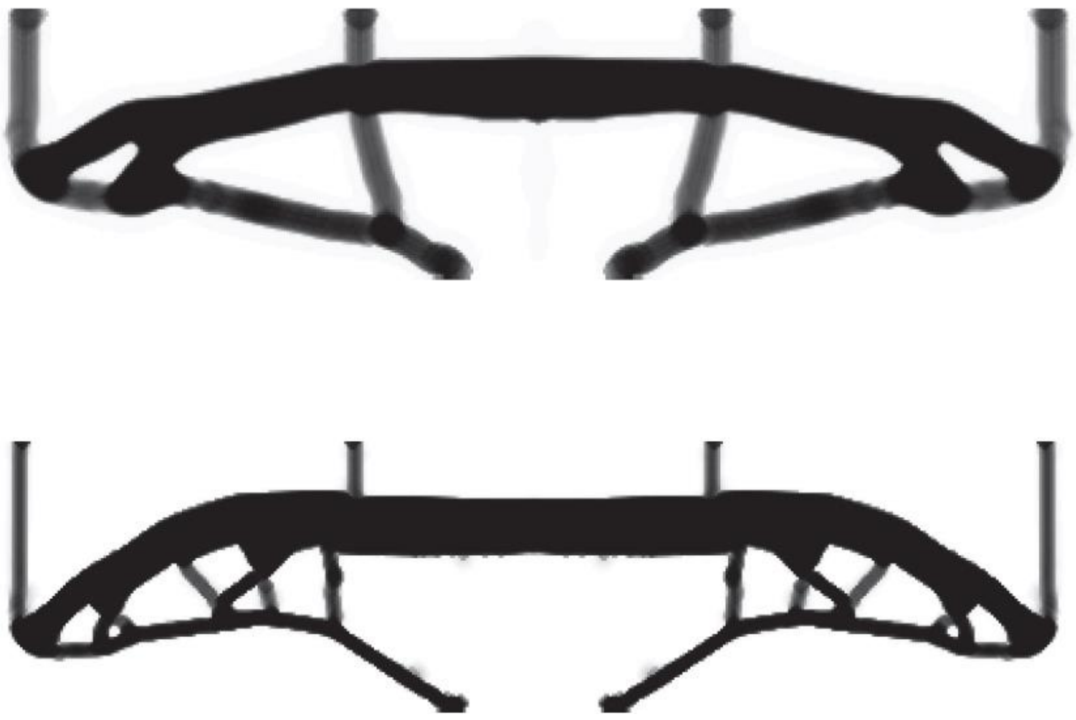
Van der Linden, 2015

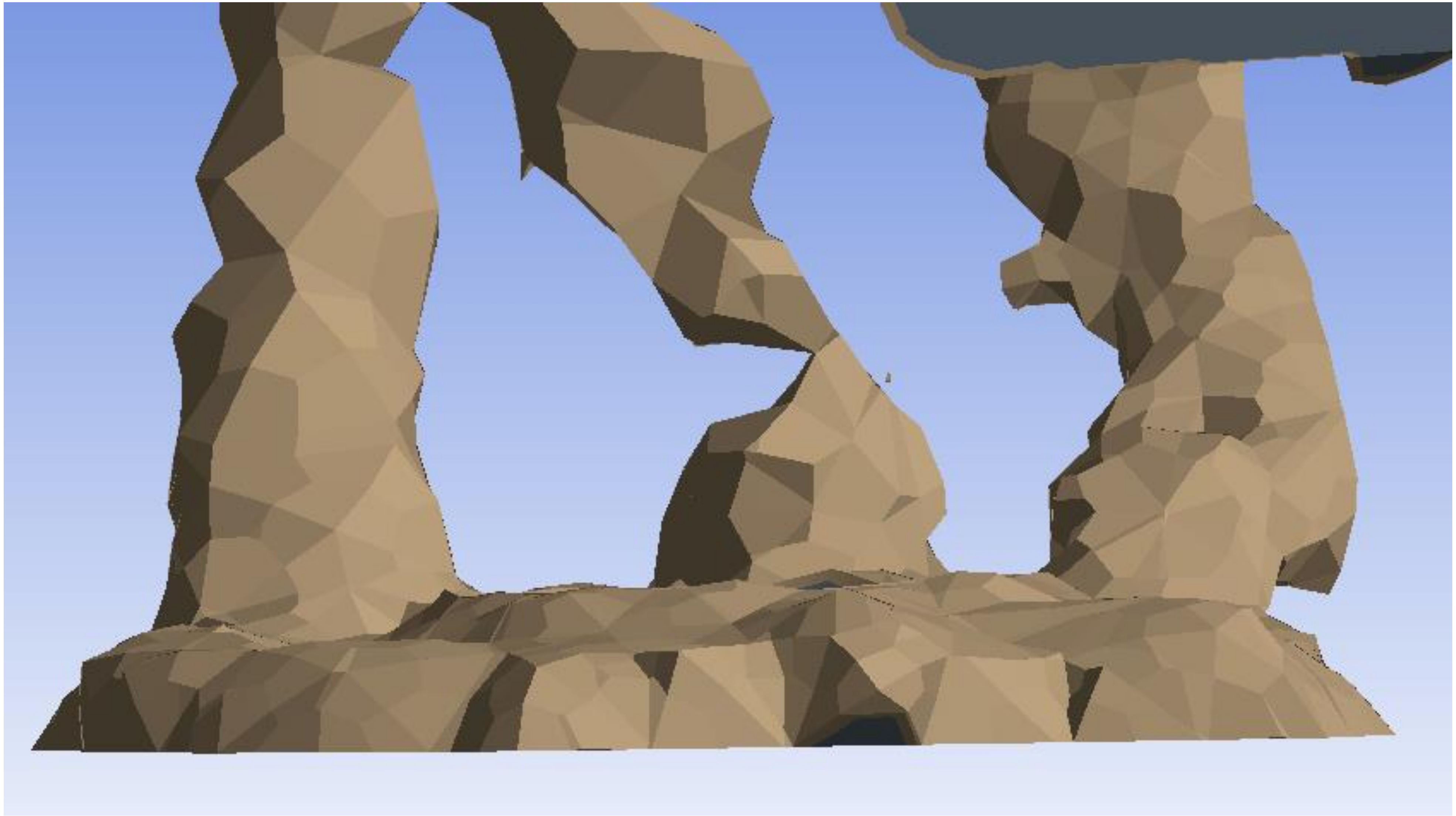
Further Research
Hybrid steel/glass structures using dual-material Topology Optimisation



Further Research

Stress based Topology Optimisation

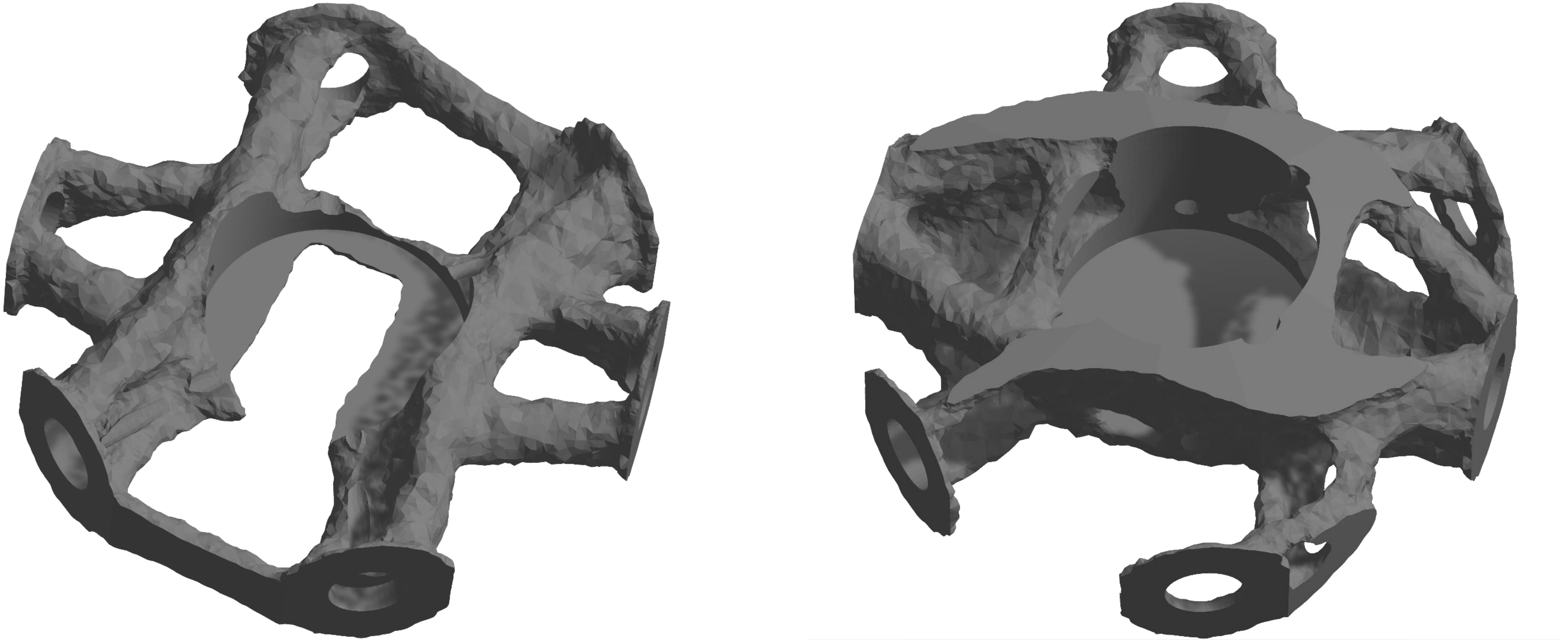




Interrupted mesh

Calculation times

Mesh size	8 mm	5 mm
Calcultion time	6 minutes	2 hours 12 minutes



Combined optimisation